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VEGETATION ABOVE A FERAL PIG BARRIER FENCE IN RAIN FORESTS OF KILAUEA'S EAST RIFT, HAWAII VOLCANOES NATIONAL PARK

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SUMMARY

Immediately after the 1993 construction of a barrier fence to block the movements of feral pigs in forests of Kīlauea's East Rift within Hawaii Volcanoes National Park (HAVO), a systematic framework of transects and plots was established for collection of baseline vegetation data upslope of the fence. Distribution and estimated abundance of the most invasive alien plant species were determined. The most widespread alien grass species was Hilo grass (*Paspalum conjugatum*); although it typically had low estimated cover values, this grass was almost ubiquitous. The most common invasive alien tree species was strawberry guava (*Psidium cattleianum*); it was found along transects in the western half of the study area, where its cover was estimated as 5-25% or 25-50%. Firetree (*Myrica faya*) occurred less frequently and had lower cover values than strawberry guava. Two other invasive woody species were found at low frequency or in limited areas; yellow Himalayan raspberry (*Rubus ellipticus*) was restricted to the slopes of Kāne Nui o Hamo, and cane tibouchina (*Tibouchina herbacea*) occurred infrequently at widely scattered localities. Alien plant frequencies from the current survey were compared with those from a previous plant survey in 1988. A third of the alien plant species along transects, including firetree, yellow raspberry, and strawberry guava, had very similar frequencies on both surveys. Frequency of Hilo grass and scaly swordfern (*Nephrolepis multiflora*) increased greatly in the study area between the two surveys. Some of the observed changes in vegetation may have been influenced by recent disturbance to the forests by cinder deposits from Pu`u `Ō`ō in an earlier phase of the current eruption.

The locations of rare native plants were mapped along transects, and numbers were compared with those from the previous survey of 1988. The endangered pendent kihi fern (*Adenophorus periens*) was not relocated on Park transects; this species may have disappeared from the slopes of Kāne Nui o Hamo in the last five years. Koli`i (*Trematolobelia grandifolia*), a "species of concern" has persisted on Kāne Nui o Hamo, and its current size class structure indicates a stable population. The 12 rare plant species that were observed on East Rift transects were concentrated in several sites, including Kāne Nui o Hamo, forests south and west of Nāpau crater, relatively open forest southeast of the 1840 flow, and the southwest corner of the study area near the Nāulu Trail. Frequencies of `ōhā (*Clermontia* spp.), indicator species for pig damage in Hawai`i, were relatively high overall in the study area, although the impact of pig predation was indicated by the paucity of terrestrial plants and a low freqeuncy of large *Clermontia*. Remonitoring a subset of transects after 1.5 years revealed that terrestrial *Clermontia* declined in frequency, while epiphytic plants increased over the same period.

Tree fern density in the study area was 38/100m^2, and the trunk height class of 1-2 m was well represented in East Rift forests. A higher density of tree ferns was observed in the western half of the study area, primarily due to the greater number of tree ferns >1m. There were fewer tree ferns on the lower halves of three main transects than were found on the upper reaches, farthest away from the barrier fence and upslope from uluhe-dominated forest. `Ōlapa (*Cheirodendron trigynum*) appeared to be an inconsistent indicator species for pig activity. This important rain forest tree was maintaining a stable population in East Rift forests, despite the long-term presence of feral pigs there. Differences in `ōlapa density were noted in the western versus the eastern, unprotected part of the study area, where lower numbers of terrestrial `ōlapa saplings were seen. When compared with the upper transect

reaches, fewer `ōlapa saplings were found along the lower portions of the three main transects, in the area near the open end of the barrier fence.

Vegetation cover and woody plant density of recently pig-disturbed sites were examined in 1994 using 39 vegetation plots, and a subset of 26 plots was remonitored 1.5-2 years later. The vegetation of disturbed East Rift forests was found to be poor in native woody plant species, and ground cover was very sparse. In the interval between monitoring, the cover of two alien species (Hilo grass and scaly swordfern) increased dramatically. Early succession indicates that these two plants will become dominant components of ground cover in pig-disturbed areas. Little change was noted in native woody plant density overall, but several native species, including tree ferns, displayed increases over the 1.5 year monitoring period.

Feral pig density, estimated from frequency of pig activity, was low in the East Rift study area (averaging 1.9 pig/km^2), even before systematic control efforts began. Quarterly pig activity monitoring revealed an increase in activity along Park transects until the end of 1993, followed by a steady decline to 2.4 pig/km^2 by the end of the study in January 1996. Data from this study suggest that the Park's snaring efforts reduced the feral pig population in the most protected, interior part of the forest upslope of the barrier fence within two years of the project initiation. Success in lowering pig density was not observed on transects at or beyond the open terminus of the barrier fence, indicating that pig ingress continued throughout the study. The current survey may only be considered a baseline study of vegetation and pig activity in managed East Rift forests. Future remonitoring may be needed to evaulate the success of this management effort in promoting long-term recovery of native vegetation.

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INTRODUCTION

Pigs (*Sus scrofa*) were first brought to the Hawaiian islands by the colonizing Polynesians who became the Hawaiians. Domestic pigs were certainly present in the villages and cultivated areas of the Hawaiians who lived in and near the current study area. While the relatively small Polynesian pig may have been found wild in the mountains away from human habitation (Diong 1983; Ellis 1969), these pigs are not thought to have done extensive damage to native vegetation of the uplands. English domestic pigs were introduced to the Hawaiian Islands by Captain Cook in 1778, and pigs were subsequently released by other Europeans (Tomich 1986). The small Polynesian pig was eventually replaced by introduced European pig stocks (Diong 1983). Feral pigs became established on eight of the main Hawaiian Islands, as well as Laysan, but they persist today on only six islands. Hawai`i Island has the largest and most widely distributed population of feral pigs (Tomich 1986).

Feral pigs are "the major current modifiers of Hawaiian forests" (Stone 1985). These animals disturb native forests by rooting and exposing bare soil, trampling native plants, and dispersing alien plant seeds (Cooray and Mueller-Dombois 1981; Smith 1985). Feral pigs also directly consume native plants and may contribute to the rarity of certain palatable species or groups of species, such as the fern *Marattia douglasii* and *Clermontia* spp. (Diong 1983; Stone 1985; Stone and Loope 1987).

Several decades ago, the National Park Service recognized that feral pigs were a serious threat to the natural resources of rain forests within Hawaii Volcanoes National Park (HAVO) (Baker 1979). Despite the removal of many thousands of feral pigs between 1930 and 1971 (Katahira *et al.* 1993), the Park's feral pig population remained in the thousands in the early 1980s (Stone and Loope 1987). Following the earlier successful example of feral goat control within the Park, HAVO managers began a systematic pig control program in 1980 (Katahira *et al.* 1993). By 1987, nine management units totaling 78 km^2 were enclosed with fences, and pig removal within them had been achieved. Systematic fencing and pig removal continued in the Park, and by 1996, feral pigs had been excluded from approximately 30% of the potential pig habitat within the Park (National Park Service 1996). The goal of pig management in the National Park is eradication and restoration of disturbed native ecosystems (Hone and Stone 1989).

The forests of Kīlauea's upper East Rift have long suffered from the effects of feral pigs. Until the closure of the Chain of Craters Road by lava flows from the Mauna Ulu eruption (1969-74), these forests were relatively accessible to hunters, and pig populations received some hunting pressure from citizen hunters, although this may not have been enough to prevent the increase of the pig population (Stone and Loope 1987). When the Chain of Craters Road was closed by the eruption, East Rift forests were less accessible to many hunters, and pig populations almost certainly increased. The realigned road opened after the cessation of the Mauna Ulu eruption, but was closed again in 1986, when lava from the ongoing Pu`u `Ō`ō eruption crossed the coastal road near the eastern Park boundary, cutting off access from the lower Puna District. Systematic management of feral pigs in the Park's East Rift forests began in February 1993, when a barrier fence stretching from the Mauna Ulu flows to a point southeast of Nāpau Crater was completed. An exclosure was not initially planned for the East Rift because of the uncertainties associated with such a geologically active area; it was assumed that a certain level of pig ingress would occur at the open eastern end of the barrier fence (Stone 1992). Control strategies may change in the future, when the sixteen-year-long Pu`u `Ō`ō eruption ceases. After the East Rift barrier fence was constructed, systematic pig control work began. Corral-type pig traps were constructed and baited, and staff hunting was carried out between June and September, 1993. Snaring began in August, 1993, and this project continued through 1996 with one hiatus in 1995 (H. Hoshide, pers. comm. 1996).

The primary objective of the current study was to evaluate the early response of both native and non-native vegetation to the reduction of feral pigs in the rain forests above the barrier fence. The monitoring data presented in this report (collected in 1993-96) are considered to be baseline data that will be more valuable when compared to a similarly collected data set at some future time. Information from previous surveys of alien plants and rare native plants in forests of the East Rift (Anderson *et al.* unpublished a) was compared with the current data to provide some assessment of vegetation trends in the area prior to pig control. Data on bird populations and invertebrates in East Rift forests were collected by others as a part of the same overall research project; these data will be presented in separate reports (Sarr *et al.* unpublished; Foote *et al.* in prep.a; Foote *et al.* in prep.b).

THE STUDY AREA

The study area is the forested portion of the Upper East Rift Zone of Kīlauea Volcano within Hawaii Volcanoes National Park, stretching from Makaopuhi Crater and Kāne Nui o Hamo shield to a point east of Nāpau Crater, between the elevations of 700 m (2,300 ft) and 1,000 m (3,200 ft) (Fig. 1). This region of the Park is within Puna District and includes parts of two Hawaiian land divisions or ahupua`a: Pānau Nui and Kamoamoa. The 1993 barrier fence was constructed in rain forests of Kīlauea's Upper East Rift Zone to protect the upslope area from feral pigs. The fence line begins at a rough finger of `a`ā from one of the Mauna Ulu flows south of Makaopuhi Crater and extends eastward 4.2 km (2.65 miles) to a point at 700 m (2,300 ft) elevation southeast of Nāpau Crater. The Mauna Ulu flows are a large expanse of bare lava on the western side of this fence line; these flows present a 4.5-km-wide barrier to pigs. The eastern side of the fence nearest the active Pu`u `Ō`ō vent was temporarily left open. The area above the feral pig barrier fence extending to the Park's boundary with Kahauale`a on the north was the focus of this study. Some vegetation and pig activity data were collected in the forests of Kahauale`a, a State-owned parcel of land directly north of the study area.

Geology and Soils

Kīlauea is a young and active volcano; more than 90% of its surface is younger than 1,100 years. The study area substrates are primarily the Kāne Nui o Hamo flows, which are dated at 500-750 years (Holcomb 1987). These flows had their origin at the parasitic shield volcano of Kāne Nui o Hamo, in the northwestern quarter of the study area, and are primarily pāhoehoe rather than `a`ā (Holcomb 1987). The 1840 flow is a prominent feature between Makaopuhi and Nāpau Craters; no vegetation sampling was done here because of the difficulty in penetrating the dense uluhe (*Dicranopteris linearis*) of this historical flow. Other historic flows within the study area date from 1963, 1965, and 1968, and a large expanse of the Mauna Ulu flows of 1969-74 bounds the study area on the west and north (Macdonald *et al.* 1983). East of the study area are very recent flows from the ongoing eruption of Pu`u `Ō`ō that began in 1983 and continues to the present. By 1985, this eruption had become "the most voluminous historical eruption of Kīlauea" (Wolfe *et al.* 1987). Tephra and ash deposits from the early episodes of the Pu`u `Ō`ō eruption have accumulated throughout the study area, but are greatest in the northeast quarter, downwind of the vent. Within the study area, tephra has accumulated on the forest floor; in places the tephra layer is nearly 0.5 m thick.

The substrate of the Kahauale`a forest just north of Nāpau Crater consists of `Aila`au flows, a series of flows dating from 350-500 years BP that had their origin at Kīlauea Iki (Holcomb 1987). This lobe of Kahauale`a forest north of the Park boundary is nearly surrounded by recent Mauna Ulu flows.

Throughout most of the study area, soils have been mapped as Ke`ei extremely rocky muck, a series of thin organic soils over pāhoehoe. Soils of this series are usually less than 254 mm (10 inches) in depth and are highly permeable. Rock outcroppings range from 25-50% of the soil surface

(Sato *et al.* 1973). The Ke`ei series is part of a soil association (Kekake-Ke`ei-Kiloa) that covers a large part of both Puna and South Hilo Districts and also occurs in the uplands of Ka`ū, South Kona, and North Kona (U. S. Department of Agriculture 1971). Below the study area, near the Kalapana Trail, soils are mapped as extremely rocky muck of the Kona soil series. The 1840 lava flow and more recent flows are mapped as miscellaneous land types with little or no soil covering. The soil series of the study area were evaluated at a reconnaissance level that involved little field checking (Sato *et al.* 1973). Recent, more field-oriented soil surveys focused on the Park will provide more reliable information.

Climate

The climate of the study area is that of a humid montane rain forest (Doty and Mueller-Dombois 1966). The mean annual rainfall of this region of Kīlauea ranges between 2,000 and 4,000 mm (Giambelluca *et al.* 1986). The climate of the upper East Rift is not strongly seasonal, but at sites both upslope and downslope of the study area, summer months tend to have less rainfall than do winter months (Doty and Mueller-Dombois 1966; Hawaii State Department of Land and Natural Resources 1970). In one short-term study of rainfall and tree growth in the study area, the months of January and February had particularly high rainfall (Cuddihy *et al.* 1986). Drought conditions are not typical in this area, but prolonged dry periods do occur.

Temperatures are typically warm in this low to middle elevation study site. The mean annual temperature of the study area falls between 18° C (65° F) and 22° C (72° F) (Hawaii State Department of Land and Natural Resources 1970). Inversely to rainfall, temperatures are higher in the summer months than during the winter. Winds are often from the northeast, as this windward area is strongly influenced by the Northeast Trade winds. The lower portion of the study area experiences strong on-shore and off-shore breezes throughout a typical diurnal period.

Vegetation

Most of the study area, including the upper slopes south of Makaopuhi and Nāpau Craters, was mapped in 1982 as closed tall `ōhi`a (*Metrosideros polymorpha*) forest with an understory of mixed native trees, tree ferns, and shrubs; this vegetation type has persisted as mapped nearly twenty years ago. The 1840 lava flow was mapped as a low-stature `ōhi`a forest with an understory of uluhe, and an area southeast of Nāpau Crater was classified as an open forest of `ōhi`a with a lower layer of native trees, shrubs, and tree ferns. The lower reaches of the study area were mapped as mesic open `ōhi`a forest with native trees and shrubs, as well as alien shrubs and grasses (Jacobi unpublished); much of this lower, open forest is dominated by uluhe today, and uluhe has intensified on the 1840 flow. An updated East Rift vegetation mapping project has recently been undertaken by Resources Management personnel (Loh and Tunison in prep.).

An even earlier vegetation map and profile classified the upper reaches of the study area as closed `ōhi`a/tree fern forest and the lower forests at 610 m (2,000 ft) elevation as open `ōhi`a/uluhe/broomsedge (*Andropogon virginicus*) forest (Mueller-Dombois 1966). This latter type was considered a transition forest between humid montane rain forest and evergreen seasonal forest at lower elevation.

Much of the upper part of the study area, particularly near the Park's boundary with Kahauale`a, is covered by recent lava flows. The most recent flows are nearly barren; others support pioneer vegetation of lichens (especially *Stereocaulon vulcani*), ferns, and young `ōhi`a lehua trees. A number of small kīpuka in these new lava flows are covered with remnant forests of `ōhi`a.

Past Land Use

Pānau Nui and Kamoamoa, the two land divisions or `ahupua`a of the study area, were inhabited by Hawaiians at the time of European contact, and the area was populated by hundreds of people when visited by William Ellis in 1823 (Ladefoged *et al.* 1987). Hawaiians continued to live in villages within these land divisions until the middle to late 1800s; by this time disease had greatly reduced the Hawaiian population, the 1868 earthquake and tidal wave had destroyed coastal villages, and the change from a subsistence lifestyle to a money economy had driven many people off the land (Allen 1979). In the 1850s, at least five families were living in the "uplands" of Pānau Nui, southeast of Makaopuhi Crater within the current study area; six other families had houses downslope on the top of Hōlei Pali (Allen 1979). Past land uses in the study area were farming, forest timber cutting, and extraction of tree fern fiber or pulu for export to the mainland.

During the last century, the pulu industry may have been particularly detrimental to the forests of the study area. Pulu, the soft reddish "hairs" or scales of the young fern fronds and stipe bases, was collected from tree ferns, dried, and baled to be shipped to North America for use as mattress and pillow stuffing (Cuddihy and Stone 1990). During pulu collection, tree ferns were often cut down or pushed over (Hillebrand 1888), a practice that must have opened up the understory of the rain forest. In the Kīlauea area, the pulu industry lasted from 1851 to 1884, when several hundred thousand pounds were collected annually (Neal 1965). In 1860, a group of pulu dealers leased the entire Pānau ahupua`a for its tree ferns (Allen 1979). Fifty to seventy-five were employed in pulu collecting and processing at the "Pulu Factory" near Nāpau Crater (Doerr 1932). The industry failed in the 1880s, when superior stuffing materials replaced pulu.

Other past land uses of the study area were goat and cattle ranching. Goats were present in this part of Puna by the 1840s (Ladefoged *et al.*1987), and goat ranching began in Pānau Iki and adjacent land divisions as early as 1862 (Allen 1979). By 1900, thousands of goats were being harvested each year in Pānau and Kealakomo ahupua`a by area residents (Williams 1990). Feral goats persisted in this area even after the Kalapana Extension became part of Hawaii Volcanoes National Park. Feral goats were recognized as a serious problem within the Park lowlands (Baker and Reeser 1972), and the animals were reduced to remnant levels throughout the Park by the 1980s. Cattle ranching began in Kamoamoa, east of the study area, in the 1880s (Ladefoged *et al.* 1987), despite the fact that this region of Puna was considered to be very poor pasture (Williams 1990; Allen 1979). Cattle ranching ceased in the area now included within the National Park after the Kalapana Extension was authorized in 1938 and the Park Service began to acquire land. Several parcels of the extension, including most of the study area, were added to the Park between 1938 and 1961 (National Park Service 1985). In the 1960s, the Puna Forest Reserve northeast of the study area supported many head of stray or feral cattle (Tomich 1986); the adjacent forests of Kahauale`a had feral cattle as late as the mid 1980s. Today, feral cattle are not known from forests within the Park, but they may persist in forests of adjacent lands.

METHODS

Sampling Scheme and Data Collection

Several of the main transects used to collect vegetation data in 1992 through 1994 (transects 1, 2, 2A, 2C, and 3) were relocated from an earlier study of East Rift forests (Anderson *et al.* unpublished a). In the earlier study, transects were placed 1-1.5 km apart, as measured on the Nāpau Trail or on a line extended from the trail toward Pu`u `Ō`ō. The Nāulu Trail above its junction with the Kalapana Trail was used as the first transect. The distance of 1 km from the trail and first transect was measured, and a random number within 100 m centered on the measured point was chosen for the starting point of the second transect. The third transect was originally placed approximately 1.25 km from the second, on the east side of Pua`ialua Crater. Additional transects were established during the current study. One of these was transect 3A; this was placed 1 km east of transect 3, again with the starting point established by a random number within 100 m. Other transects were set out along the barrier fence midway between existing transects, as measured along the fence line; except for rare plant sightings, these fence line transects were not primarily used for collection of vegetation data. Four transects were placed in Kahauale`a, north and northeast of Nāpau Crater, adjacent to the Park study area. Kahauale`a transects were 500 m apart, measured along the Nāpau Crater/Pu`u `Ō`ō trail. Most transects followed the azimuth of those in the earlier study (140° True); exceptions were transect 1 (Nāulu Trail) and transects within small kīpuka (transect F8) or lobes of forest on Kāne Nui o Hamo (transect 2C). Transects were of variable length, but the three primary transects of the study area above the barrier fence were surveyed for 2,400 m.

Alien Plants - Plants considered alien or non-native are those listed as naturalized in Wagner *et al.* (1990), with the exception of two species formerly regarded as alien but now viewed as indigenous. These are ricegrass (*Paspalum scrobiculatum*) and pōpolo (*Solanum americanum*). Botanical nomenclature follows that of Wagner *et al.* 1990. Alien plant frequency and abundance data were collected in flagged 10-m long segments of transects in a belt 5 m wide centered on the transect. Presence/absence of all alien plant species was noted. Cover of each alien plant species was estimated using the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). Abundance estimates from 5 x 10 m segments were averaged for mapping alien plant presence and cover-abundance in 100-m long increments. Only one observer (LWP) collected alien plant frequency and abundance data in the current study (1992-94). Alien plant data were collected by five observers in 1988 (Anderson *et al.* unpublished a); one observer (LWP) participated in both 1988 and 1993 surveys. For comparison with the 1988 data, alien plant data from the 10-m segments were compiled in 50-m increments.

Rare Plants - Individuals of all rare native plant species were counted on all surveyed East Rift transects in a belt 5 m wide. All endangered or candidate endangered plant species known from the area, as well as any of approximately 50 additional rare Park species (Higashino *et al.* 1988), were searched for and noted when found. Rare plants were mapped in 100-m increments along the transects; a few rare plants found on access trails or the fence line were also mapped as off-transect sightings. Where possible, the number of rare species found in the current study were compared with similar data from 1988. The 1988 rare plant data were collected in 50-m increments of the transects.

Clermontia Frequency and Density - Members of the lobelioid genus *Clermontia* were counted along transects in a belt 5 m wide. Field counts were made in 10-m increments of the transect and were combined into plots 100 m long. Both *C. parviflora* and *C. hawaiiensis* were present in the study area. As young plants are difficult to assign to species, counts combined all *Clermontia* within plots. Plants were recorded in height classes of <0.1, 0.1-0.5, >0.5-1, >1-2, and >2 m. Three rooting site categories were distinguished: terrestrial, epiphytic < 1m above ground, and epiphytic ≥1 m above ground. The original data were collected in 1992 and 1993, primarily in winter and spring; *Clermontia* plants were recounted along a subset of the same transects in winter 1994 using the same size classes and rooting site categories.

Density of Tree Ferns - Tree ferns or hāpu`u (*Cibotium* spp.) were counted in plots at 200-m intervals along primary transects, starting at 0 m; tree fern plots were in the same localities as `ōlapa plots and bird census stations. Plot size was 5 x 20 m, with the long axis measured along the transect. Tree ferns were counted in trunk height or length classes of <0.5, 0.5-1, >1-2, and >2 m. Small tree ferns without trunks were also counted. Upright ferns were measured from the ground to the growing tip at the base of fronds. Decumbent tree ferns had the length of the trunk measured along the ground. At least two species of tree ferns (*Cibotium glaucum* and *C. menziesii*) were present in the study area but were not distinguished in the density plots.

`Ōlapa (*Cheirodendron trigynum*) Density - In 1992-94, `ōlapa trees were counted in 10 x 20 m plots at 200-m intervals along primary transects (transects 1A, 2, 2A, 3, 3A), starting at 0 m. `Ōlapa were also counted in plots along short transects near the fence line (1AU, 1B, 2B). Plots were measured along the transect 20 m; they were 10 m wide centered on the transect. All `ōlapa rooted within the plot were counted in basal diameter classes of <1, 1-5, >5-10, >10-20, >20-30, and >30-40, >40-50 and >50 cm. `Ōlapa seedlings and saplings <1 cm diameter were counted in height classes of <0.1, 0.1-0.5, >0.5-1, or >1-2 m and three rooting site categories were distinguished: terrestrial, epiphytic <1 m from the ground, and epiphytic ≥1 m above the ground. Because of relatively low numbers of individuals, some of the diameter and height classes were combined for analysis and comparisons.

Vegetation in Pig-Disturbed Plots - Thirty-nine plots, 10 x 10 m in size, were established along or near transects in sites that had been recently disturbed by pigs in 1994. This total included six plots along transects in Kahauale`a, adjacent to the Park. Within these plots all woody plants were counted in size classes. Woody plants <1 cm basal diameter were counted in three height classes (<0.1 m, 0.1-1 m, >1 m). The rooting site of these seedlings and saplings was also noted (terrestrial vs. epiphytic). Woody plants >1 cm basal diameter were counted in diameter classes of 1-5 cm, >5-10 cm, >10-20 cm, >20-40 cm, >40-80 cm and >80 cm. Tree ferns were counted in four height/length classes of <0.5 m, 0.5-1 m, >1-2 m, and >2 m. Ground cover was measured with the point-intercept method (Mueller-Dombois and Ellenberg 1974), using a point frame 1.25 m tall and 1 m wide, with five points spaced at 20-cm intervals. Five lines (each 10 m long) were used to sample each plot at 1, 3, 5, 7, and 9 m, measured from the eastern corner of the east/west baseline. Internal plot transects ran north/south across each plot. Each line sampled 50 points, for a total of 250 points in each plot. A subset of 26 plots was remonitored for ground cover and woody plant density in December 1995 and January 1996, approximately 1.5 to 2 years after the original sampling.

Soil Depth - Soil depths were measured along the three longest primary transects (2, 3, and 3A). Sites of measurement were every 200 m, starting at 0 m. At each site, ten soil depths were measured at randomly-selected points along a 20-m stretch of transect. Measurements were made 2 m off transect (on the east side) to avoid measuring compacted soils along the path. When treefalls or other obstructions were present east of the transect, measurements were taken west of the transect. To measure soil depth, a thin steel rod was inserted into the soil until it hit rock or other obstruction, and the length of the rod below the surface was measured after removal.

Feral Pig Activity - Feral pig activity was monitored quarterly along five primary transects (1, 2, 2A, 3, and 3A) in the Park study area, as well as along the four transects in Kahauale`a (8-11). The first monitoring was done in June 1993, four months after the barrier fence was constructed and before pig control efforts began (H. Hoshide, pers. comm. 1996); quarterly monitoring continued until June, 1995, after which one last monitoring was carried out in January, 1996. There was a total of 10 sampling periods. Pig activity criteria used were those developed by C.P. Stone and others at Hawaii Volcanoes National Park (Anderson and Stone 1993, 1994). Pig activity data were collected in 10-m-long increments of transects in a belt 5 m wide. Pig density in the study area was calculated using a model for all fresh sign developed for use in a variety of vegetation types (Anderson and Stone 1994).

RESULTS

Alien Plant Species Distribution and Abundance

Forty-eight alien species were found along the primary transects above the barrier fence, including two questionably indigenous species (ricegrass and pōpolo). Eight alien species occurred at high frequency along transects within the study area or are known elsewhere as invasive plants; these include three grass species, four shrubs or trees, and one species of fern.

Broomsedge (*Andropogon virginicus*) - This North American grass has been on Hawai`i Island for more than 70 years (Wagner *et al.* 1990), but became widespread and abundant within Hawaii Volcanoes National Park only in the 1960s (Fosberg 1966). During the 1992-94 study, broomsedge was relatively common along Park transects and occurred in 18.3% of 10-m segments. The grass was distributed primarily along the westernmost and upper-elevation transects above the barrier fence, but was also scattered at a few sites along the central and eastern transects (2, 3 and 3A) (Fig. 2). Cover of broomsedge was typically < 1% or 1-5%, but at more than 50 sites estimated cover was either 5-25 or 25-50%, and a few sites had greater than 50% ground cover (Fig. 3). Areas with greatest broomsedge cover were exposed sites at the upper and lower extremes of the Nāulu Trail (transect 1), in the narrow central part of the Figure 8 Kīpuka, and near the top of Kāne Nui o Hamo (Fig. 2). By contrast, the small Kahauale`a transects had an overall broomsedge frequency of only 9.3%, centered on the western transects near the forest/lava flow interface. Cover estimates of broomsedge were usually <5% in the Kahauale`a forest (Fig. 4).

Meadow Ricegrass (*Ehrharta stipoides*) - Meadow ricegrass, a species native to Australia, New Zealand, and the Philippines (Wagner *et al.* 1990), is common in upper elevation pastures, where it is considered a useful forage species (Whitney *et al.* 1964). The grass was extremely rare in the Park study area, with a frequency of only 0.2%. Meadow ricegrass was noted on only two transects at widely separated sites, where its cover was <1%. Although highly invasive at more mesic upland sites, this grass does not seem to pose a threat to the rain forests of the East Rift.

Hilo Grass (*Paspalum conjugatum*) - The most abundant grass along East Rift transects was Hilo grass, an early introduction to Hawai`i from tropical America (Wagner *et al.* 1990). In 1992-94, Hilo grass was distributed throughout the study area, where its frequency was 61% along Park transects (in 10 m increments). Cover values of this grass were highest (5-25%) along the Nāulu Trail (transect 1), near the barrier fence, and along the middle-elevation stretches of the three longest transects (2, 3, and 3A) (Fig. 5). While the grass was typically estimated at <5% cover, more than a fifth of Park transect segments had Hilo grass cover >5%. Cover values as high as 50-75% were noted at a few sites (Fig. 3). Hilo grass was also common along Kahauale`a transects (Fig. 5), where its frequency was 42.4 % and its estimated cover was generally <5% (Fig. 4).

Firetree (*Myrica faya*) - Firetree or faya tree, a fast-growing species intentionally introduced to Hawai`i from the Azores, Madeira, and the Canary Islands (Wagner *et al.* 1990), has been present in the Park since the 1960s (Fosberg 1966). The East Rift forests are on the easternmost edge of firetree distribution in Hawaii Volcanoes NP (Camrath *et al.* in press). During the 1992-94 survey, firetree occurred with a frequency of 8% along Park transects above the barrier fence. Most firetree sightings were along the Nāulu Trail (transect 1) and the adjacent transect 1A, and scattered trees were noted along transect 2 (Fig. 6). Firetree was not seen south of Nāpau Crater or east of the 1840 lava flow, although this area was included in the current range expansion of firetree by Camrath *et al.* (in press.). No firetree was noted on the slopes of Kāne Nui o Hamo, even though large, fruit-bearing trees were present along the trail south and east of Makaopuhi Crater. Firetree was absent from the transects in Kahauale`a, north of the Park.

Within most transect segments with firetree, the cover of the species was rated at <1% or 1-5% (Fig. 3). Higher cover estimates were noted for a quarter of the segments containing firetree; these were concentrated along the Nāulu Trail and in the upper forests south of Makaopuhi Crater. This area was formerly adjacent to the old Chain of Craters Road before it was covered by Mauna Ulu lava flows in 1969-74; firetree likely invaded the East Rift forests along the old road corridor. Very high cover of firetree still exists along the upper Kalapana Trail near the barrier fence and in forests south of the fence near the original Chain of Craters Road.

Strawberry Guava or Waiawi (*Psidium cattleianum*) - An early introduction to the Hawaiian Islands (Nagata 1985), strawberry guava has invaded many low elevation rain forests and is considered one of the most disruptive alien plant species in the State (Smith 1985; Loope *et al.* 1992). In 1992-94, strawberry guava was the most widespread alien woody plant in forests of the study area, where its frequency of occurrence was 35.5% on Park transects above the barrier fence. Strawberry guava was distributed along all transects above the fence, but highest cover values were along and near the Naulu Trail and on the lower third of transect 2 just above the barrier fence (Fig. 7). In these areas estimated cover of guava was often 5-25% or even 25-50%, cover estimates rarely achieved elsewhere in the study area. Overall, more than 80% of the Park transect segments with strawberry guava had cover estimates of <5% (Fig. 3). Transects in Kahauale`a also supported strawberry guava, but here guava frequency was only 10.3%, and estimated cover never exceeded 5%. Strawberry guava was noticeably less common on the easternmost Kahauale`a transects, as well as on the lower half of the easternmost Park transect (3A). Much of the strawberry guava in the study area displayed foliar damage due to sulfur dioxide from volcanic fumes or "vog."

Yellow Himalayan Raspberry (*Rubus ellipticus*) - A recent introduction to Hawai`i, yellow Himalayan raspberry is a large, prickly, thicket-forming shrub native to India (Wagner *et al.* 1990). Within the East Rift study area, yellow Himalayan raspberry was found only on the slopes of Kāne Nui o Hamo (Fig. 8). Consequently, the frequency of occurrence of this raspberry was low (1.6%) along Park transects above the barrier fence. With one exception, the cover of yellow raspberry never exceeded 5% on the two transects where it occurred (Fig. 3). The 1992-94 distribution of yellow Himalayan raspberry suggests that this disruptive species has only recently invaded the Park's East Rift forests and that Park managers may still have an opportunity to control the pest on Kāne Nui o Hamo and prevent its invasion of lower-elevation rain forests.

Cane Tibouchina (*Tibouchina herbacea*) - A shrub in the melastome family, this South American species was first detected in Hawai`i in 1977 (Wagner *et al.* 1990), but has subsequently invaded wet forests on both Hawai`i and Maui. Cane tibouchina was not known from Hawaii Volcanoes until an extensive 1988 survey of East Rift forests (Anderson *et al.* unpublished a; Higashino *et al.* 1988). In 1992-94, cane tibouchina occurred at very low frequency (1.2%) along Park transects. Only a few sites along transects 2, 3, 2A, and 2C supported scattered individuals or small clumps of cane tibouchina with little cover (Fig. 9). A few additional observations of the weed were made near the Nāpau Crater campground, on the western side of Nāpau Crater, and along the barrier fence line. Based on forays away from transects, the area south of the 1840 lava flow near 760 m (2,500 ft) elevation appears to be the center of tibouchina distribution within the study area. This area consistently displayed a high level of feral pig activity, because it contains a persistent waterhole. Frequency of cane tibouchina was low on the western Kahauale`a transects (1%), where the shrub was noted at only three sites (Fig. 9). The source of the Park's cane tibouchina infestation is not known, but the plant may have invaded from Kahauale`a Natural Area Reserve north of the study area, where the species has been well established for several years (S. Perlman, pers. comm.).

Scaly Swordfern (*Nephrolepis multiflora*) - A robust, terrestrial fern native to the old world tropics (Lamoureux 1982), scaly swordfern is found in many Park habitats and is abundant on exposed lava fields (Wagner 1995). In the 1992-94 survey of forests above the pig barrier fence, scaly swordfern occurred with a frequency of 36.6% along Park transects. The fern was widely distributed within the study area, but was most common below 855 m (2,800 ft) elevation (Fig. 10). Swordfern cover values were greatest along the lower half of the easternmost transects (3 and 3A), where estimated cover was usually >25% (Fig. 3, Fig. 10). Swordfern cover was typically <5% along transects in the western half of the study area, even along the disturbed trail corridor, and scaly swordfern was largely absent from the slopes of Kāne Nui o Hamo and the upper half of transect 2. Scaly swordfern had a high frequency of occurrence along Kahauale`a transects (52.6%), but estimated cover here was usually <5%, and sites with swordfern cover >25% were uncommon (Fig. 4, Fig. 10). The abundance of scaly swordfern in the easternmost parts of the current study area is likely due to past heavy cinder-fall originating from the active vent at Pu`u `Ō`ō (1983-86).

Other Alien Plants - In addition to the eight invasive alien species discussed above, forty other alien or questionably indigenous plant species were noted along Park transects. Most of these (30) were herbaceous species with low frequencies; these included nine grasses or sedges, six composites, four ferns, and eleven other herb (forb) species. Eight shrub species and one woody vine were infrequently noted, and African tulip tree (*Spathodea campanulata*) was sighted at only one locality. Among the grasses, the most common species was yellow foxtail (*Setaria gracilis*), which occurred in 6.8% of Park transect segments, primarily in the lower reaches of the study area and along the Nāulu trail. This species is not generally thought to be an important pest in Hawai`i (Smith 1985). Glenwood grass (*Sacciolepis indica*) had a frequency of 3.2% along Park transects. Two other grasses that are invasive elsewhere in the Park, Vasey grass (*Paspalum urvillei*) and bush beardgrass (*Schizachryium condensatum*), were very rare in the study area with transect frequencies <1%. These and the other uncommon grasses and sedges seen during the survey, do not appear to pose any threat to the forest vegetation of the East Rift.

No members of the Sunflower family (Asteraceae) were very common in the study area, and none seemed to be particularly invasive; valerian-leaved fireweed (*Erechtites valerianifolia*), with a frequency of 1.9%, was most often encountered. Apart from scaly swordfern, the most common alien fern was *Deparia petersenii* (previously known as *Athyrium japonicum*); this fern had a frequency of 4.6%. This relatively recent introduction is widespread in other Park rain forests disturbed by pigs (Pratt and Abbott in prep.). The only other herbs with a frequency of occurrence >3% were bamboo orchid (*Arundina graminifolia*) (3.4%), a common component of open lowland vegetation, and Chinese ground orchid (*Phaius tankervilliae*) (3.1%), a terrestrial species found in rain forests throughout the Park. Neither orchid is considered to be highly invasive or disruptive.

Apart from the highly invasive woody species discussed in the previous sections, only one shrub had a frequency >2% in the Park above the barrier fence. Thimbleberry (*Rubus rosifolius*) occurred along Park transects with a frequency of 10.2%. This weedy Asian shrub is nearly ubiquitous in wet forests below 1,830 m (6,000 ft) elevation on Hawai`i Island (Gerrish *et al.* 1992), but is generally considered to be less disruptive than other alien *Rubus* species (Smith 1985). Other shrub species scattered along Park transects included Asiatic butterfly bush (*Buddleia asiatica*), lantana (*Lantana camara*), melastoma (*Melastoma candidum*), and sourbush (*Pluchea symphytifolia*); some of these are invasive in drier, more open areas, but they are not serious invaders of rain forest. Liliko`i (*Passiflora edulis*), a woody vine, was noted along transects with a frequency of 3.6%; this relatively innocuous species has probably spread into the Park from cultivated areas east of the Park.

Changes in Frequency of Alien Plants over Five Years - Frequency and cover data on alien plants were also collected during the extensive survey of East Rift forests in 1988 (Anderson *et al.* unpublished a). A subset of the original transects was relocated and used for the present study, and for the purposes of comparison, presence/absence data were evaluated in 50-m increments, the form in which frequency data were collected in the 1988 survey. Table 1 presents the number of occurrences, frequency, and Chi-square (X^2) comparison of the number of occurrences of 39 alien species found in both 1988 and 1992-94. Frequency data presented here for 1992-94 differ from those presented earlier because of the larger transect increment size and because several transects were newly established in the study area in 1992 and thus were not used for comparison with 1988 data.

More than a third of the alien plant species found along transects during both surveys had very similar frequencies in both 1988 and 1992-94. Most of these 15 alien species were relatively innocuous weeds, such as valerian-leaved fireweed, Chinese ground orchid, and St. John's wort (*Hypercium* spp.). A few of the species with constant frequency were typical trail weeds, including African smutgrass (*Sporobolus africanus*) and beggar's tick (*Desmodium* spp.). However, firetree, strawberry guava, and yellow Himalayan raspberry, three of the most invasive alien plants of the study area, also had unchanged frequencies over the five-year period. While all three of these species are considered highly invasive and disruptive, none appears to be rapidly expanding in the study area.

Nearly half of the alien plant species found along transects decreased in frequency over the five years between surveys. While many of these decreased only slightly, seven weed species displayed a significant downward change in frequency from 1988 to 1993 (Table 1); these included a grass, a fern, one small herb, and four shrub species. Broomsedge occurred along transects in 1992-94 less than half as often as the grass was detected in 1988 (X^2 = 45.8, p = 0.000). The alien fern *Macrothelypteris torresiana,* a common fern of sparsely vegetated lava flows, was seen only a third as often in 1992-94 as it was in 1988 (X^2 = 6.8, p = 0.009). Oriental hawksbeard (*Youngia japonica*), a small herb common to trails and disturbed areas, was also significantly less frequent in the current survey than in 1988 (X^2 = 4.1, p = 0.043). The four shrubs that showed significant decreases along transects during the period between surveys were Asiatic butterfly bush (X^2 = 16.8, p = 0.000), sourbush (X^2 = 9.8, p = 0.002), thimbleberry (X^2 = 12.5, p = 0.000), and vervain (*Stachytarpheta* spp.) (X^2 = 7.5, p = 0.006). With the exception of thimbleberry, the decreasing shrub species are typical inhabitants of disturbed, open areas, such as trails and artificial clearings. The observed decrease in frequency may be related to the continued recovery of the forest canopy following the cessation of cinder-fall from the active vent of Pu`u `Ō`ō.

Only eight alien species showed an increase in frequency between 1988 and 1992-94 (Table 1); most of these displayed only small increases that are unlikely to represent an important trend in invasion on the East Rift. The species that increased slightly were primarily herbaceous plants, including bamboo orchid, the sedge *Cyperus halpan*, bush beardgrass, and the possibly indigenous ricegrass. Liliko`i, a liana, also increased slightly in frequency along transects. Of more concern are three highly invasive aliens that displayed a significant increase over the five-year period. Hilo grass frequency increased from 52.4 to 84.6% in the period between surveys (X^2 = 48.5, p = 0.000), and scaly swordfern went from 35.1 to 44.7% (X^2 = 3.6, p = 0.057). The cause of the spread and intensification of scaly swordfern is unknown.

Of particular concern was the significant increase of the recent invader cane tibouchina (X^2 = 6.0, p = 0.015). In 1988, this melastome was found at only one site within the current study area (0.5% frequency), on Kāne Nui o Hamo (transect 2A). By 1992, cane tibouchina was noted with a frequency of 4.8% along transects (in 50-m increments), and had spread beyond Kāne Nui o Hamo to transects 2 and 3, as well as to sites on the western edge of Nāpau Crater (such as cleared campsites in the Nāpau campground) and a number of localities near the barrier fence. In 1988, the shrub was also found at a few sites along transects east of the current study area; the status of the weed in these unmonitored areas is unknown, but it is likely to have intensified here as well. This alien plant certainly deserves further monitoring and will likely require some level of control effort, as it may become an important weed in Park rain forests.

TABLE 1. Frequency of occurrence of alien plant species in 50-m increments along East Rift forest transects in 1988 and 1992-94.

Species	# Segments With Sp. 1988	Frequency (%)	#Segments With Sp. 1992	Frequency (%)	X^2 Corr.	P
Ageratina riparia	36	17.3	22	10.6	3.3	0.066
Andropogon virginicus	126	70.0	58	27.9	49.9	0.000*
Arundina graminifolia	20	9.6	27	13.0	0.9	0.353
Axonopus affinis	29	13.9	22	10.6	0.8	0.370
Buddleia asiatica	36	17.3	9	4.3	16.8	0.000*
Conyza bonariensis	8	3.4	3	1.4	1.5	0.222
Crassocephalum crepidioides	6	2.9	1	0.5	2.3	0.127
Cuphea carthagenensis	22	10.6	13	6.3	2.0	0.158
Cyperus halpan	1	0.5	5	2.4	1.5	0.217
Deparia petersenii	9	4.3	6	2.9	0.3	0.599
Desmodium spp.	11	5.3	10	4.8	0.1	1.000
Ehrharta stipoides	4	1.9	3	1.4	0.0	1.000
Erechtites valerianifolia	21	10.1	20	9.6	0.0	1.000
Gnaphalium purpureum	1	0.5	1	0.5	0.0	1.000
Hypericum spp.	11	5.3	9	4.3	0.05	0.819
Kyllinga brevifolia	4	1.9	2	1.0	0.2	0.681
Ludwigea palustris	3	1.4	1	0.5	0.3	0.615
Macrothelypteris torresiana	23	11.1	8	3.9	6.8	0.009*
Melinis minutiflora	4	1.9	0	0	2.3	0.132
Myrica faya	24	11.5	27	13.0	0.09	0.765
Nephrolepis multiflora	73	35.1	93	44.7	3.6	0.057*

TABLE 1 (Continued). Frequency of occurrence of alien plant species in 50 m increments along East Rift forest transects in 1988 and 1992-94.

Species	# Segments With Sp. 1988	Frequency (%)	#Segments With Sp. 1992	Frequency (%)	X^2 Corr.	P
Paspalum conjugatum	109	52.4	176	84.6	48.5	0.000*
Paspalum scrobiculatum	2	1.0	4	1.9	0.2	0.681
Passiflora edulis	24	11.5	31	14.9	0.8	0.385
Phaius tankervilliae	28	13.5	31	14.9	0.8	0.779
Physalis peruviana	5	2.4	3	1.4	0.1	0.721
Pluchea symphytifolia	40	19.2	18	8.7	8.8	0.003*
Psidium cattleianum	133	63.9	140	67.3	0.4	0.536
Rubus ellipticus	12	5.8	12	5.8	0.0	1.000
Rubus rosifolius	116	55.8	79	40.0	12.5	0.000*
Sacciolepis indica	44	21.2	31	14.9	2.3	0.126
Schizachryium condensatum	1	0.5	5	2.4	1.5	0.217
Setaria gracilis	29	13.9	32	15.4	0.08	0.782
Solanum americanum	1	0.5	1	0.5	0.0	1.000
Spathodea campanulatum	1	0.5	1	0.5	0.0	1.000
Sporobolus africanus	6	2.9	6	2.9	0.0	1.000
Stachytarpheta spp.	19	9.1	15	7.2	0.3	0.591
Tibouchina herbacea	1	0.5	10	4.8	6.0	0.015*
Torenia asiatica	1	0.5	1	0.5	0.0	1.000
Youngia japonica	22	10.6	9	4.3	5.0	0.025

* Significant at the 95% level.

Rare Plant Species

Jewel orchid (*Anoectochilus sandviencis*) and `awapuhi a Kanaloa (*Liparis hawaiensis*) - One of only three orchid species endemic to Hawai`i, jewel orchid or honohono is widely distributed in wet forests of most of the main Hawaiian Islands (Wagner *et al.* 1990), but is extremely rare on windward Hawai`i Island. Recently, both jewel orchid and `awapuhi a Kanaloa were added to the list of "species of concern" maintained by the U. S. Fish and Wildlife Service (U. S. Fish and Wildlife Service 1999). In the East Rift study area, jewel orchid was found on transect only in the small, figure-eight shaped kīpuka between Makaopuhi and Nāpau Craters (Fig. 11). Two individual jewel orchids were also noted along an access trail to transect 3, just southwest of Nāpau Crater. The terrestrial orchid has persisted at the kīpuka site for five years, as the 1988 survey also found the species here (Anderson *et al.* unpublished a). Jewel orchid was previously seen on the trail to Nāpau Crater (Fagerlund and Mitchell 1944) and within a small crater west of Nāpau (Fagerlund and Mitchell unpublished). No orchids have been recently sighted along this well-used trail, and a recent survey of East Rift pit craters failed to locate jewel orchid in the small crater near Nāpau (Belfield 1998). Jewel orchid formerly occurred in a pig-free kīpuka near the Park's eastern boundary (Higashino and Stone 1982); this kīpuka was subsequently covered by lava and cinder from Pu`u `Ō`ō in 1983-84. Apart from East Rift rain forests, jewel orchid is currently found in the Park only in `Ōla`a Forest (Pratt and Abbott 1997), and remains one of the rarest native plants in Hawaii Volcanoes.

`Awapuhi a Kanaloa (*Liparis hawaiensis*), a second endemic orchid species native to the Park, was not seen along East Rift transects in 1992-94, nor was it sighted on the previous survey in 1988 (Anderson *et al.* unpublished a). This terrestrial orchid formerly grew near Nāpau Crater and on the slopes of Kāne Nui o Hamo (Fagerlund and Mitchell unpublished), but was not seen at either site during a recent survey of pit craters (Belfield 1998). The last documented sighting of `awapuhi a Kanaloa on the East Rift was made at the boundary kīpuka in 1982 (Higashino and Stone 1982).

Hame (*Antidesma platyphyllum*) - A small tree in the spurge family (Euphorbiaceae), hame or mehame occurs in mesic to wet forests at lower elevations on all the main Hawaiian Islands (Wagner *et al.* 1990). While not generally considered a rare plant, hame is uncommon in Hawaii Volcanoes National Park, perhaps because of a lack of appropriate habitat. Only 42 hame trees were counted along Park transects above the barrier fence, and two trees were seen just below the fence (Fig. 12.). Hame trees were distributed below 760 m (2,500 ft) elevation in the central and eastern part of the study area. Only five hame trees were found at one site on the edge of Kahauale`a. Hame may have increased in abundance in the last five years, as only six trees were noted within the current study area in the 1988 survey (Anderson *et al.* unpublished a). Hame has never been common within the Park; the species was not even listed as present in earlier checklists (Fagerlund and Mitchell 1944; Fosberg 1966).

Lobelioids (*Clermontia* spp., *Cyanea* spp., and *Trematolobelia grandifolia*) - Native members of the lobelia subfamily of the bellflower family (Campanulaceae) are an important component of the Hawaiian flora, comprising 10% of all native flowering plant species (Wagner *et al.* 1990). Weak-stemmed and succulent shrubs or small trees, the lobelioids are particularly susceptible to damage and destruction from the feeding and rooting activities of feral pigs (Diong 1983; Stone 1985). Two species of `ōhā were found in the East Rift rain forests; the rarer of the two is `ōhā kēpau (*Clermontia hawaiiensis*). This small tree was present at few sites: the west side of Nāpau Crater, along the Nāulu Trail south of Makaopuhi Crater, and at three sites in the western half of the study area forests north of the barrier fence (Fig. 13). Only 32 individual plants were seen along transects and trail; most of these were relatively young, vigorous trees. Seedlings were noted beneath a large, epiphytic `ōhā kēpau tree near the barrier fence. This species was formerly a candidate endangered species, but is now considered too common to warrant such status. Nonetheless, the `ōhā kēpau remains a rare plant in Hawaii Volcanoes National Park, where it occurs in forests of `Ōla`a (Pratt and Abbott 1997) and Kīlauea Crater Rim. Recently, 28 `ōhā kēpau of various sizes were discovered within the crater of Pu`u Huluhulu, a cinder cone surrounded by Mauna Ulu lavas, west of the study area (Belfield

1998). This sighting, midway between Kīlauea Crater Rim and the East Rift, indicates that `ōhā kēpau formerly had a larger range when stands of contiguous forest existed along the East Rift.

A second species of `ōhā (*Clermontia parviflora*) was much more abundant and widely distributed within the East Rift study area (Fig. 14). More than 700 individuals of this species were counted along the primary Park transects of the study area, and an additional 50 were noted along short transects near the barrier fence. Kahauale`a transects also displayed a high density of `ōhā; 276 plants were counted along four short transects. `Ōhā plants were particularly numerous on the slopes of Kāne Nui o Hamo and in the upper-elevation forests of the study area. This species is not rare in Park, where it is widespread in suitable forest habitat of `Ōla`a and Kīlauea Crater Rim, but it is susceptible to damage from feral pigs. Results of comparisons of `ōhā frequencies and size classes in different parts of the study area are presented in the following section.

Koli`i (*Trematolobelia grandifolia*) was previously a Category 2 candidate for endangered species status (U. S. Fish and Wildlife Service 1990), but is now considered a "species of special concern" (U. S. Fish and Wildlife Service 1999). An Hawai`i Island endemic, this koli`i is distributed in the Kohala Mountains, Mauna Kea, and Mauna Loa, in addition to sites within the Park (Wagner *et al.* 1990). Koli`i is a shrub, usually unbranched, with large inflorescences of curved white flowers followed by dry capsules. Like other koli`i, the Park species is monocarpic and short-lived; plants die after producing flowers and fruits (St. John 1982). During the survey of East Rift forests, only 49 koli`i plants were counted along transects, and these were concentrated at two sites on the slopes of Kāne Nui o Hamo (Fig. 13). Most of these plants (47%) were 50 to 100 cm tall, and about a third (37%) were in the >10 to 50 cm height category (Table 2). Very few seedlings <10 cm tall were observed (2 plants), but large plants >1-2 m tall comprised 12% of the total on-transect population. Most of the observed koli`i plants were epiphytic on tree fern trunks or tree logs, but more than a third (39%) were terrestrial. None of the Kāne Nui o Hamo koli`i was fertile during the survey months of October and January. The koli`i plants of Kāne Nui o Hamo were typically taller than those of the Park`s `Ōla`a Forest, and terrestrial plants were more common than in the `Ōla`a population (Pratt and Abbott 1997). More individuals grow off-transect near the top of the old shield volcano; at least 100 koli`i plants were present on Kāne Nui o Hamo in 1993.

Table 2. Height and rooting category of koli`i (*Trematolobelia grandifolia*) on Kāne Nui o Hamo transects in forests of the East Rift.

Height Class (cm)	Rooting Category	Number of Plants	% of Total
< 10	Terrestrial	1	2.0
< 10	Epiphytic	1	2.0
< 10	All	2	4.1
10-50	Terrestrial	8	16.3
10-50	Epiphytic	10	20.4
10-50	All	18	36.7
> 50-100	Terrestrial	8	16.3
> 50-100	Epiphytic	15	30.6
> 50-100	All	23	46.9
>100-200	Terrestrial	2	4.1
>100-200	Epiphytic	4	8.2
>100-200	All	6	12.2

The koli`i population on Kāne Nui o Hamo appears to have decreased since the area was last surveyed in 1988. Almost twice as many koli`i plants (85) were observed along the same transects during this earlier, more extensive survey of East Rift rain forests (Anderson *et al.* unpublished a). However, the short-lived nature of the species makes direct comparisons of plant numbers over time difficult, since the length of the monocarpic life cycle of the species is not known. While no longer being considered for endangered species status, koli`i remains a rare plant species within the Park and deserves some level of monitoring in protected forests of the East Rift and `Ōla`a.

A third genus of lobelioid known from forests of the East Rift, *Cyanea* or hāhā, was not observed along transects in 1992-94. During the interval between surveys in 1988 and 1992, individuals of *Cyanea degeneriana* disappeared from one kīpuka between Makaopuhi and Nāpau Craters. Even though the same transect was relocated and resurveyed, this small, weak-stemmed shrub was not found. *Cyanea degeneriana* has also been lost from two other East Rift sites destroyed by cinder and lava from the Pu`u `Ō`ō eruption: the pig-free "boundary kīpuka" and Pu`u Kamoamoa, a hill east of Nāpau Crater (Higashino and Stone 1982) . The species persists in East Rift forests only within a small crater west of Nāpau (Belfield 1998), although other protected sites in the area may also provide refuge. *Cyanea pilosa* subsp. *longipedunculata,* another species of hāhā that is relatively rare in the Park, was not found along East Rift transects in 1988 (Anderson *et al.* unpublished a) or in 1992-94. This species has been observed within East Rift forests only in sites inaccessible to feral pigs, such as the pit crater of Kāne Nui o Hamo, the small crater west of Nāpau (Belfield 1998), and the now-destroyed kīpuka of Pu`u Kamoamoa (Higashino and Stone 1982).

<u>Hahala (*Cyrtandra paludosa*), `ilihia (*Cyrtandra platyphylla*), and other *Cyrtandra*</u> - The genus *Cyrtandra* is widespread in Asia, Australia, and the Pacific. There are 53 currently recognized species in Hawai`i, and more than 60 putative hybrids have been detected (Wagner e*t al.* 1990). These members of the African violet family (Gesneriaceae) are typically weak-stemmed shrubs or small trees with white flowers, fleshy white fruits, and varying degrees of hairiness on leaves and stems. At least three different species were found within the study area forests: hahala or *Cyrtandra paludosa*, `ilihia or *C. platyphylla*, and a third species that is probably a hybrid (possibly the entity formerly called *C. ramosissima*). Hahala or moa, a small shrub native to low elevation forests of Hawai`i, Maui, O`ahu, and Kaua`i, was uncommon in the study area, where 17 plants were found along Park transects, and only 6 were noted in Kahauale`a (Fig. 15). The species was concentrated in the forest lobe on the northeast of Kāne Nui o Hamo, in a small kīpuka east of Kāne Nui o Hamo, and at few sites in the upper half of the easternmost transect 3A. Another uncommon *Cyrtandra*, assumed to be a hybrid, was found in the same areas as hahala and was also noted as scattered individuals just above the barrier fence; 13 plants were counted along Park transects. This putative hybrid also occurred in low numbers (11) along the Kahauale`a transects north of the Park (Fig. 15).

The species of *Cyrtandra* most frequently seen in the study area was `ilihia, a large shrub with conspicuously hairy, heart-shaped leaves. This is a common species in wet forests of both Maui and Hawai`i, and is widespread in wet forests throughout Hawaii Volcanoes National Park. Two hundred twenty-nine individuals of this species were observed along Park transects, mostly in the upper half of the study area. Kāne Nui o Hamo, the figure-eight kīpuka, and the forests southeast of Nāpau Crater were particularly rich in this species. `Ilihia plants were also numerous along Kahauale`a transects, where 128 individuals were counted (Fig. 16).

Comparisons of *Cyrtandra* numbers encountered during the two surveys are difficult to make, since the current study used several new transects to sample the western half of the area surveyed in 1988. The total number of *Cyrtandra* of any species observed in 1988 was 225 (Anderson *et al.* unpublished a), very similar to the 1992-94 total of 259 plants along Park transects (excluding Kahauale`a). Apparently, no great loss of *Cyrtandra* has taken place in the study area in the five-year period between surveys.

The putative hybrid encountered within the study area deserves more attention. If the hybrid is the same entity as the formerly recognized species *C. ramosissima*, it represents a cross between the common *C. platyphylla* and the rare *C. giffardii* (Wagner *et al.* 1990), a listed endangered species known from `Ōla`a Forest (Pratt and Abbott 1997). *Cyrtandra ramosissima* was collected in Makaopuhi Crater by Fagerlund and Mitchell in 1943 (Fosberg 1966) and in a crater near Nāpau by the same collectors (Fagerlund and Mitchell unpublished). Similar plants were found in the same location near Nāpau in 1996 (Belfield 1998). Belfield also collected *C. lysiosepala* in this pit crater near Nāpau; this species was not seen within the East Rift study area in the 1992-94 survey.

Kāmakahala (*Labordia hedyosmifolia*) - Members of this endemic Hawaiian genus in the logania family (Loganiaceae) are typically shrubs or small trees with yellow flowers and capsular fruits. The kāmakahala of the study area was formerly recognized as a distinct variety (var. *kilaueana*) (Fosberg 1966), which was considered a candidate for endangered species status (U. S. Fish and Wildlife Service 1976). Today varieties are not recognized, and the species is viewed as a locally common plant on four of the Hawaiian Islands (Wagner *et al.* 1990). Kāmakahala was very rare within the study area in 1992-94, where only nine plants were encountered along Park transects and access trails, and only three plants were seen in Kahauale`a (Fig. 17). There appeared to be little change in the distribution or abundance of this species since the last survey, when only ten plants were counted along Park transects (Anderson *et al.* unpublished a).

Ōpuhe (*Urera glabra*) and `Ohe (*Tetraplasandra hawaiensis*) - Ōpuhe, a tree in the nettle family (Urticaceae), is found in mesic to wet forests on most of the main islands (Wagner *et al.* 1990). The species was formerly known as *Urera sandwicensis* (St. John 1973). Only one tree was observed within the study area in 1992-94, on the boundary of the Park with Kahauale`a, northeast of Nāpau Crater (Fig. 17). During the earlier 1988 survey, the species was noted only along transects east of the current study area in forests southeast of Nāpau Crater (Anderson *et al.* unpublished a). Ōpuhe has subsequently been reported at one site within the current study area, the deep summit crater of Kāne Nui o Hamo (Belfield 1998). Ōpuhe was noted as infrequent in East Rift forests near Makaopuhi and Kāne Nui o Hamo in the 1940s (Fagerlund and Mitchell unpublished).

`Ohe, a tall tree in the ginseng family (Araliaceae) is native to wet and mesic forests of Hawai`i, Maui, Lāna`i, and Moloka`i (Wagner *et al.* 1990). The species was formerly considered rare enough to be a candidate for endangered species status (U. S. Fish and Wildlife Service 1980), and was listed as depleted and potentially endangered by Fosberg and Herbst (1975). Only three `ohe trees were observed within the current study area; one was on the Park`s boundary with Kahauale`a, just north of Nāpau Crater, and the others were at sites near 730 m (2,400 ft) elevation in forest southeast of Nāpau (Fig. 17). During the previous survey in 1988, `ohe trees were found east of the current study area in forests upslope of Lae`apuki (Anderson *et al.* unpublished a). The species has also been seen in forests immediately southeast of Nāpau Crater (Cuddihy *et al.* 1986) and is more frequently a component of lower-elevation forests east of the Park (Char and Lamoureux 1985).

`Iliahi or Sandalwood (*Santalum paniculatum*) and Neneleau (*Rhus sandwicensis*) - `Iliahi or sandalwood is well known in Hawai`i as the object of a short-lived commercial trade during the early 1800s (St. John 1947); although some Hawaiian sandalwood species were severely depleted during the period of exploitation, the species endemic to Hawai`i Island is neither endangered nor extremely rare. This Hawai`i Island species (*S. paniculatum*) is a shrub or small tree that occurs in dry woodlands from the lowlands to the subalpine zone. Two varieties of *S. paniculatum* are recognized (Stemmermann 1980); the variety found within the Park is var. *paniculatum*. More than 100 `iliahi trees were seen along study area transects; these were concentrated in the southwestern part of the study area, above and below the barrier fence (Fig. 18). `Iliahi trees were particularly noticeable along the Nāulu Trail just north of the Mauna Ulu lava flows; the forest here appears to be transitional between rain forest and mesic woodland.

Neneleau or Hawaiian sumac, a large shrub in the mango family (Anacardiaceae) is a plant of disturbed areas and open woodlands. This species was found only at the southernmost extreme of the study area below the feral pig barrier fence (Fig. 18), where a few were seen on transect north of the Kalapana trail. A second group of neneleau was noted outside the study area in a previously burned kīpuka along the Nāulu Trail. This region of the East Rift is the only known Park site with neneleau, which is more common outside the Park, particularly along roadsides near Hilo (Wagner *et al.* 1990).

Rare Plant Species Not Found in 1992-94 - Pendent kihi (*Adenophorus periens*), a small epiphytic fern in the grammitis family (Grammitidaceae), was listed as endangered in 1994 (U. S. Fish and Wildlife Service 1994). The fern is also known by the name *Oligadenus periens* (Wagner 1995). Formerly known from five Hawaiian Islands and now restricted to three, the largest known population of the fern occurs in Kahauale`a (Char and Lamoureux 1985), a Natural Area Reserve adjacent to the Park's East Rift. Pendent kihi was not found during the 1992-94 East Rift survey, despite re-survey of areas that supported the fern in 1988. On the previous botanical survey, pendent kihi was found at four sites along transect 2C on the northeast slope of Kāne Nui o Hamo (Anderson *et al.* unpublished a). These areas were searched three times in 1993, without success. The fern was not found during a search of another site in the Kāne Nui o Hamo forest where 14 pendent kihi had been sighted in a 1-ha study area more than ten years ago (Cuddihy *et al.* 1986). The fern was also not seen during a 1995 search of the crater of Kāne Nui o Hamo (Belfield 1998). Intermittent sulfur dioxide fumes from the active Pu`u `Ō`ō vent, combined with periods of drought, may have killed the pendent kihi of the Park's East Rift forests. The endangered fern has been sighted at only one other locality in the Park, within `Ōla`a Forest (P. Higashino pers. comm. 1995). A recent survey of `Ōla`a failed to find the fern (Pratt and Abbott 1997), and its current status there is unknown.

In addition to the endangered pendent kihi fern and several species of *Cyanea* discussed above, there are at least seven rare plant species previously known from forests of the Park's East Rift that were not found within the study area during the 1992-94 survey. These rare plants include one fern, two mints, one vine, and three tree species; all are either endangered, species of concern, or among those listed as rare in the Park (National Park Service 1996).

Pala or Douglas mules' foot fern (*Marattia douglasii*) is a large, terrestrial fern palatable to both humans and pigs. Formerly relatively common in middle-elevation forests (Hillebrand 1888), pala has become depleted in Park forests, possibly due to the feeding and digging activities of feral pigs (Stone 1985). The fern has become extremely rare in forests of the East Rift in recent years. Higashino and Stone (1982) found pala in the pig-free boundary kīpuka that was subsequently destroyed by lava, and Belfield (1998) noted the fern within the crater of Kāne Nui o Hamo in 1996. No pala ferns were seen along transects, trails, or plots within the study area in 1992-94.

Two rare members of the mint family (Lamiaceae) have also been previously noted in East Rift forests. *Phyllostegia vestita*, a wet forest vine endemic to windward Hawai`i (Wagner e*t al.* 1990), is rare in Hawaii Volcanoes National Park, where its distribution is centered on `Ōla`a Forest (Pratt and Abbott 1997). Formerly rated as a species of uncertain rarity (Fosberg and Herbst 1975), *P. vestita* was for a while a "species of special concern" (U. S. Fish and Wildlife Service 1997), and is now without special status. This herbaceous mint was collected along the trail to Nāpau Crater more than 50 years ago (Fagerlund and Mitchell 1944). While it is no longer extant at the trail site, Belfield (1998) found the species within the protected crater of Kāne Nui o Hamo in 1996. The plant is not known from any other sites within the East Rift study area. *Phyllostegia floribunda* is a small shrub known from four disjunct populations on Hawai`i Island (Wagner *et al.* 1990). A former candidate for endangered species status (U. S. Fish and Wildlife Service 1980), this mint is today a "species of special concern" (U. S. Fish and Wildlife Service 1997, 1999). Earlier checklists provided only vague references to this plant in "forest at Kīlauea" (Fagerlund and Mitchell 1944, Fosberg 1966), and it was not definitely known from the Park's East Rift until Belfield (1998) found the mint growing within a small pit crater near Nāpau in 1996. Unidentified species of *Phyllostegia* were noted in the Boundary Kīpuka and on Pu`u

Kamoamoa in 1982 (Higashino and Stone 1982), but the identity of these mints cannot be determined now that these kīpuka have been destroyed. *Phyllostegia floribunda* has also been reported from `Ola`a Forest (Pratt and Abbott 1997), but is not known from any other Park sites.

Kilioe (*Embelia pacifica*), an uncommon woody vine in the myrsine family (Myrsinaceae), is a "species of concern" currently known in the Park from `Ōla`a Forest (Pratt and Abbott 1997), Kīpuka Puaulu, and Kīpuka Kī (Pratt *et al.* in prep.). The vine was a component of vegetation in the Boundary Kīpuka, a wet forest near the Park's eastern boundary with Kahauale`a (Higashino and Stone 1982). Kilioe was not found by Belfield during his survey of East Rift pit craters (Belfield 1998), nor was the vine observed along transects in the current survey. Since the destruction of the Boundary Kīpuka in the early 1980s, this rare species may have been lost from forests of the East Rift.

The listed endangered `aiea (*Nothocestrum breviflorum*) was reported as a rare or infrequent tree along the Nāpau trail in the early 1940s (Fagerlund and Mitchell 1944). This tree is typically a component of dry to mesic forests, rather than rain forests. `Aiea has not been documented in the study area in the last 50 years. `Ānini (*Eurya sandwicensis*) is a shrub or small tree of the tea family (Theaceae). This former candidate endangered species (U. S. Fish and Wildlife Service 1990) was previously an infrequent component of wet forest near Makaopuhi Crater (Fagerlund and Mitchell 1944). In 1944, `ānini was collected one mile east of Kāne Nui o Hamo, where several 25- ft-tall trees were noted (Fagerlund and Mitchell unpublished). Much of this site was covered by lava flows in 1965 and 1968 (MacDonald *et al.* 1983). No `ānini trees have been sighted in surveys of the East Rift since multiple lava flows of the 1960s and 1970s (Cuddihy *et al.* 1986, Anderson *et al.* unpublished a, Belfield 1998). `Ānini was not found during the current survey, despite the placement of two transects in the general area of the 1944 sighting. `Ahakea (*Bobea timonioides*), formerly a category 2 candidate endangered species (U. S. Fish and Wildlife Service 1990) and now a "species of concern" (U. S. Fish and Wildlife Service 1999), is typically a tree of dry or mesic forests, such as the remnant Nāulu Forest on Hōlei Pali (Abbott and Pratt 1996). This rare species was also listed from wet forest in the Boundary Kīpuka (Higashino and Stone 1982) before its destruction by lava. `Ahakea was sighted during the earlier East Rift survey (Anderson *et al.* unpublished a) on transects to the east of the current study area. The present Park distribution of this tree is not fully known, as much forested area of the East Rift has been covered by lava in the ongoing eruption of Pu`u `Ō`ō.

<u>*Clermontia* Frequency and Density</u>

The most common `ōhā or *Clermontia* species of the East Rift forests is *C. parviflora,* although the rarer *C. hawaiiensis* is also present. As young *Clermontia* plants are undistinguishable, the species were combined when frequency and density data were collected along transects. In 1992-93, the most frequently observed size class of `ōhā along all primary Park transects was that of plants 0.1-0.5 m tall. For this small size class, 7.9% of segments had terrestrial *Clermontia*, 10.6% had plants epiphytic <1 m from the ground, and 3.1% had plants epiphytic at heights ≥1 m (Fig. 19A). Larger plants of any rooting site were seen far less frequently, and *Clermontia* taller than 2 m were extremely rare. The rooting site preferred by smaller size classes of *Clermontia* was the near-ground, epiphytic position on trees or tree ferns (<1 m). The larger size class of *Clermontia* 1-2 m tall was found with similar frequency in the three rooting site categories, and the very rare *Clermontia* >2 m tall were seen with equal frequency in the two epiphytic categories, but were almost never found growing terrestrially (Fig. 19A).

Kahauale`a transects displayed a high frequency of *Clermontia* in the two epiphytic categories (Fig. 19B). In 1993, Kahauale`a transects had higher frequencies of epiphytic *Clermontia* in most size classes than did an equal sample size of segments along the upper half of the two Park transects (3 and 3A) closest to the Kahauale`a forests (Figure 20). The difference was most pronounced for the 0.1-0.5 size class, where frequency along Kahauale`a transects (26%) was more than twice as high as along the nearest Park transects (11.3%) for plants rooted <1m from the ground. Likewise, plants of this size class epiphytic at sites ≥1m high were observed with a frequency of 17% on Kahauale`a transects, but occurred in only 1% of the comparable Park transect segments. Kahauale`a transects showed higher frequencies than Park transects for all size classes in the rooting category epiphytic ≥1 m. The trend was reversed for terrestrial plants; for all size classes taller than seedlings (<0.1m), the frequency of occurrence was three to six times greater on Park transects 3 and 3A than was observed in Kahauale`a. Larger plants epiphytic <1m above the ground (height classes >0.5-1, >1-2, and >2m) were also more frequently seen along Park transects than in Kahauale`a, although differences in observed frequencies were not large (Fig. 20A). *Clermontia* density (mean number/100 m segment or 500 m^2) paralleled frequency in the comparison of Kahauale`a transects with the upper part of Park transects 3 and 3A) (Fig. 20B). The mean density of plants of all size classes and all three rooting sites was 6.1 in Kahauale`a and 3.9 in the Park. Density of epiphytic *Clermontia* was higher in Kahauale`a, considerably so for those epiphytic ≥1m above the ground. However, there were almost three times more terrestrial plants along Park transects 3 and 3A than were found in Kahauale`a.

A subset of Park transects was remonitored for *Clermontia* in 1994, one year and eight months to 2.5 years after the original data collection in 1992-93. Areas remonitored were the three long transects stretching from the Nāpau Trail and Crater to a point just above the barrier fence. These transects east or near the end of the barrier fence (transects 3 and 3A) and near a persistent water source (transect 2) might have been expected to have residual pig activity even with control efforts. On these three transects, the frequency of almost every height class in the two epiphytic categories increased over the 1.5-2.5 year monitoring period (Fig. 21A); large increases in frequency of occurrence were observed in the 0.1-0.5 m height class for both epiphytic sites and in the ephemeral <0.1 m seedling class epiphytic <1m high. The difference in frequency was significant for plants epiphytic ≥1 m in the combined size classes of 0.1-1 m (X^2=5.43, p=0.020) and >1m (X^2=3.64, p=0.056). By contrast, all terrestrial height classes declined in frequency, except the seedling class <0.1 m tall. The number of transect segments supporting terrestrial *Clermontia* in 1994 was significantly lower than in 1992-93 for the combined size class of 0.1-1m (X^2=6.59, p=0.010) and for large plants >1m (X^2=6.61, p=0.010). Overall *Clermontia* density of plants in any size class and rooting site increased from 1.7/500 m^2 to 3.0/500 m^2 on the three transects (Fig. 21B). As was true of frequency of occurrence, increases were large in the two epiphytic categories. Because seedlings were also considered (and this group showed an increase) the density of terrestrial plants appeared to remain constant at 1.9/500 m^2 over the monitoring period.

<u>Density of Tree Ferns (*Cibotium spp.*)</u>

Tree ferns or hāpu`u are an important component of the understory of the Park's East Rift forests. Tree fern density was sampled throughout the study area to establish a baseline for future comparisons and to evaluate the impact of feral pigs on native vegetation. Both hāpu`u pulu (*Cibotium glaucum*) and hāpu`u `i`i (*C. menziesii*) were found in study area forests, but species distinctions were not made during data collection in the tree fern density plots. The mean density of tree ferns in the study area above the feral pig barrier fence was 38.1/100 m^2. More than half of the tree ferns in the typical plot were <1 m tall; the mean number of ferns < 0.5 m in height was 10.6, and the mean number of ferns in the 0.5-1 m height class was 9.9 (Fig. 22). The height class of 1-2 m was well represented in sample plots, with a mean of 14.2. Few tree ferns achieved heights >2m; the plot mean in this class was only 3.2/100 m^2.

There was a higher density of tree ferns in the western half of the study area than in the eastern, less protected part of the study area. The number of tree ferns per plot on transects 1A, 2A, and 2 was compared with the number/plot on transects 3 and 3A, which are east of the 1840 lava flow and at or beyond the end of the feral pig barrier fence (Fig. 1). This area beyond the fence has received no organized control of pigs; there has been no snaring or hunting by Park staff. Plots in the western half of the study area, within the intensively managed unit, had a mean of 41.4 ferns/100 m^2, while plots on the two easternmost transects averaged 34.3 tree ferns of any size. The difference in total tree fern density in the two areas (east vs. west) was significant above the 90% confidence level (t = 1.88, p = 0.0663).

Tree fern densities in plots along the three longest primary transects (2, 3, and 3A) were also compared. There was a significant difference in the density of tree ferns on these three transects ($F = 4.97$, $p = 0.0124$). The Waller Duncan k-ratio t test indicated that the easternmost transect 3A (with a mean of 30/100 m^2) had significantly fewer tree ferns than transects 2 and 3, where plots averaged 42.8 and 38.6 tree ferns/100 m^2 respectively (Table 3). The differences in total tree fern densities appeared to be due to a significantly greater number of mature tree ferns (>1m) in the two western transects ($F = 7.54$, $p = 0.0018$). There was little difference in the mean number of small tree ferns (< 1m) among the three transects ($F = 1.68$, $p = 0.2000$).

Table 3. Mean number of tree ferns (*Cibotium* spp.) in plots (100 m^2) on three transects in forests of the East Rift, compared with the Waller-Duncan k-ratio t test.

Waller-Duncan Group*	Mean No. Tree Ferns	Size Class	Transect
A	22.8	<1 m	2
A	19.7	<1 m	3
A	17.4	<1 m	3A
A	19.9	≥1 m	2
A	18.9	≥1 m	3
B	12.6	≥1 m	3A
A	42.8	All	2
A	38.6	All	3
B	30.0	All	3A

*Groups with different letters are significantly different at the 95 % confidence level.

Tree fern densities also varied along the north/south axis of the three long transects; differences were particularly pronounced on transects 2 and 3 (Fig. 23). The mean number of small tree ferns (<1m tall) was significantly greater on the upper, northern half of the three transects (23/100 m^2) than on the lower half of the transects (18.3/100 m^2), near the pig barrier fence ($t = 2.01$, $p = 0.0529$). By contrast, the mean density of tall tree ferns (≥1m) was very similar on the upper and lower portions of the three transects (17.3/100 m^2 vs 17.5/100 m^2). The total densities of tree ferns of any size did not differ significantly in the two areas ($t = 1.31$, $p = 0.1975$).

<u>Density and Population Structure of `Ōlapa (*Cheirodendron trigynum*)</u>

`Ōlapa is one of the most common native understory trees of Hawaiian rain forests, and the species is widely distributed within the study area above the feral pig barrier fence. The tree is an important host for native picture-wing pomace flies (Foote and Carson 1995). Based on an analysis of the density of `ōlapa in several size classes in all sample plots along all transects above the barrier fence, the population distribution of this tree species is a reverse J-shaped curve, indicating a relatively stable population (Fig. 24A & B). The `ōlapa size class with the greatest number of individuals was the seedling and sapling group with <1 cm diameter. The overall mean number of `ōlapa in this class was 10.2/200 $m^2$. Larger diameter `ōlapa trees were far less common than saplings; the small and medium size tree diameter classes of 1-5 cm, >5-10 cm, and >10-20 cm had almost identical means of 1.8, 1.9 and 1.9 trees/200 m^2 (Fig. 24B). Very large `ōlapa trees were very rare in the study area; the mean number of `ōlapa >20-30 cm dbh was only 0.2/200m^2, and `ōlapa >30-40 cm basal diameter were almost non-existent (0.01/200m^2).

Within the group of small `ōlapa <1 cm diameter, individuals of four different height classes were distinguished. Most abundant were seedlings <10 cm tall; the plot mean of `ōlapa in this group was 8.6/200m^2. This group is the most ephemeral size class, and seedling numbers were quite variable among plots. It is likely that results vary with the time of year, since `ōlapa reproduces seasonally, and fruits are usually present in the summer months. `Ōlapa density data were collected during summer and fall months when seedlings were germinating from the year's crop of seeds. Although far less abundant than seedlings, `ōlapa 10-50 cm tall were also well represented with a plot mean of 1.3/200m$^2$. `Ōlapa saplings in >50-100 cm and >100-200 cm height classes were extremely uncommon with plot means <1/200m^2. The distribution of small `ōlapa <1 cm basal diameter paralleled that of the entire population with a reverse J-shaped curve (Fig. 24A), indicating a population of `ōlapa with adequate reproduction. Most of the `ōlapa seedlings <0.1 m tall were either terrestrial or epiphytic below 1 m, and a lesser number of seedlings were epiphytic above 1m (Fig. 25A). In the three taller height classes, with one exception, the mean number of saplings was similar in the three rooting categories. `Ōlapa 10-50 cm tall were often seen as epiphytes in trees above 1 m from the ground, thus the mean for this group exceeded that of terrestrial or lower epiphytic plants in the height class. `Ōlapa trees with diameters of 1 to 20 cm were most often found as terrestrial plants or low epiphytes (Fig. 25B).

As with tree ferns, the mean number of `ōlapa in plots in the western half of the study area (transects 1A, 2, and 2A) was compared with `ōlapa means in the eastern half near the edge of the feral pig barrier fence (transects 3 and 3A) (see Fig. 1). There was a higher density of small `ōlapa with diameters <1 cm in the western half of the study area than in the eastern, less protected part of the study area (Table 4). Even though the mean number of all `ōlapa <1 cm bd was six times greater along transects in the western half than the mean in plots of the easternmost transects, the difference was not significant (t = 1.23, p = 0.2313). Four height classes of small `ōlapa (<0.1 m, 0.1-0.5 m, >0.5-1 m, and >1-2 m) and three rooting sites (terrestrial, epiphytic <1 m above ground, and epiphytic >1 m above ground) were distinguished during data collection, but the height classes were condensed into two groups for data analysis. In the ephemeral height class of <0.1 m, means of `ōlapa seedlings in all three rooting categories were much greater along western transects than on the easternmost transects, but individual plots showed great variability in `ōlapa seedling numbers. In the sapling height class of 0.1-2 m, a significantly greater number of terrestrial `ōlapa were seen in plots of the western half of the study area (t = 2.12, p = 0.0421), but epiphytic `ōlapa in this size class were more abundant (although not significantly so) in plots along the eastern transects (Table 4).

For all classes of `ōlapa with a diameter >1 cm, the mean number of trees was greater in eastern plots than in those of the western half of the study area. These differences were particularly pronounced for the small and medium-size `ōlapa trees; in these two groups there were five to six times more `ōlapa in the average eastern plot than in those of the western transects. Differences appeared to be significant for `ōlapa with 1-10 cm dbh (t = 3.19, p = 0.0036), >10-20 cm dbh (t = 2.90, p = 0.0069), and >20-40 cm dbh (t = 2.75, p = 0.0111). (Table 4).

`Ōlapa densities in plots along the three longest primary transects (2, 3, and 3A) were also compared. Among the small size classes (<1 cm bd), there were no clear trends across the three transects (Table 5). A greater number of terrestrial seedlings (<0.1 m tall) were found on transect 3A (F = 3.3, p = 0.0494), but seedlings epiphytic below 1 m were more abundant on transect 2 (F = 5.7, p = 0.0076). In the terrestrial 0.1-2 m height class, a greater number of `ōlapa saplings were counted in plots of transect 3A (F = 4.5, p = 0.0188). Even though the other rooting categories of the sapling height class also showed greater numbers in plots along transect 3A, differences among the three transects were not significant (Table 5). Among the larger size classes (>1 cm bd), the mean number of `ōlapa trees was consistently greatest on the easternmost transect 3A when compared with transects 2 and 3 (Table 5).

Table 4. A comparison of the mean number of `ōlapa (*Cheirodendron trigynum*) in several size classes and rooting categories within plots of the western versus the eastern study area.

Area	Size Class Height	Rooting Site	N	Mean # `Ōlapa	SD	t	Probability
West	<0.1m	terrestrial	25	10.6	45.8	1.09	0.2881
East	<0.1 m	terrestrial	25	0.6	1.5		
West	<0.1 m	epi <1 m	25	10.7	34.9	1.51	0.1432
East	<0.1 m	epi <1 m	25	0.1	0.5		
West	<0.1 m	epi >1 m	25	2.1	7.0	1.52	0.1428
East	<0.1 m	epi >1 m	25	0	0		
West	0.1-2 m	terrestrial	25	0.2	0.5	2.12	0.0421*
East	0.1-2 m	terrestrial	25	0	1.3		
West	0.1-2 m	epi <1 m	25	0.3	0.6	1.89	0.0690
East	0.1-2 m	epi <1 m	25	1.0	1.7		
West	0.1-2 m	epi >1 m	25	0.2	0.4	1.97	0.0600
East	0.1-2 m	epi >1 m	25	1.4	3.1		
West	<0.1-2 m	all	25	24.0	81.7	1.23	0.2313
East	<0.1-2 m	all	25	3.9	5.7		
	Size Class ba diameter						
West	1-10 cm	all	25	1.0	2.1	3.19	0.0036*
East	1-10 cm	all	25	6.2	7.9		
West	10-20 cm	all	25	0.6	1.2	2.90	0.0069*
East	10-20 cm	all	25	2.5	3.2		
West	20-40 cm	all	25	0	0	2.75	0.0111*
East	20-40 cm	all	25	0.5	0.9		
West	1-40 cm	all	25	1.5	3.0	3.41	0.0020*
East	1-40 cm	all	25	9.2	10.9		

* Significant at the 95% confidence level.

Table 5. Mean number of `ōlapa (*Cheirodendron trigynum*) in plots (200 m^2) on three transects in forests of the East Rift, compared with the Waller-Duncan k-ratio t test.

Waller-Duncan Group*	Mean # `Ōlapa	Size Class Height	Rooting Site	Transect
A	1.3	<0.1 m	Terrestrial	3A
AB	0.2	<0.1 m	Terrestrial	2
B	0.1	<0.1 m	Terrestrial	3
A	1.1	<0.1 m	Epi <1 m	2
B	0.2	<0.1 m	Epi <1 m	3
B	0.1	<0.1 m	Epi <1 m	3A
A	0.4	<0.1 m	Epi >1 m	2
A	0.0	<0.1 m	Epi >1 m	3
A	0.0	<0.1 m	Epi >1 m	3A
A	0.0	0.1-2 m	Terrestrial	2
A	0.3	0.1-2 m	Terrestrial	3
B	1.3	0.1-2 m	Terrestrial	3A
A	0.4	0.1-2 m	Epi <1 m	2
A	0.8	0.1-2 m	Epi <1 m	3
A	1.3	0.1-2 m	Epi <1 m	3A
A	0.1	0.1-2 m	Epi >1 m	2
A	1.2	0.1-2 m	Epi >1 m	3
A	1.8	0.1-2 m	Epi >1 m	3A
		Diameter Size Class		
A	0.8	1-10 cm	All	2
AB	4.1	1-10 cm	All	3
B	8.5	1-10 cm	All	3A
A	0.3	10-20 cm	All	2
AB	1.6	10-20 cm	All	3
B	3.4	10-20 cm	All	3A
A	0.0	20-40 cm	All	2
AB	0.3	20-40 cm	All	3
B	0.8	20-40 cm	All	3A

* Groups with different letters are significantly different at the 95% confidence level.

There was a pronounced difference in the number of large `ōlapa in plots along the upper stretches versus the lower halves of the three longest transects (2, 3, and 3A) above the feral pig barrier fence (Fig. 26B), but differences were less noticeable for small plants (Fig. 26A). There was no significant difference in the number of `ōlapa seedlings of any rooting category along the two halves of the transects. `Ōlapa saplings (0.1-2 m tall) were more abundant along the upper halves of the three transects, although only those epiphytic above 1 m showed a significant difference in the two areas ($t = 2.10$, $p = 0.0508$). All diameter classes of large `ōlapa (≥ 1 cm) were more abundant in plots along the upper halves of transects 2, 3, and 3A, but differences were significant only for `ōlapa with diameters 1-10 cm ($t = 2.06$, $p = 0.0522$) and for all large-diameter `ōlapa combined (1-40 cm)($t = 2.23$, $p = 0.0372$).

Vegetation in Pig-Disturbed Plots

Thirty-nine quadrats (10 x 10 m) were established in areas that showed recent, heavy pig disturbance in 1994 (Fig. 27). Quadrats or plots were clustered in groups of three to six. Two clusters were located just above the pig barrier fence near transects 1AU and 2, and two more groups of plots were placed near the mid-point of transect 2, not far from a permanent pool of standing water. The forest between the Nāulu Trail (transect 1) and transect 1A was sampled with two groups of three plots. The farthest eastern plots within the Park were along the lower half of transect 3. In the upper reaches of the study area, plots were placed along transects 2A and 2C, as well as along an access route to the top of transect 3; this densely forested area southwest of Nāpau Crater was sampled with two clusters of plots. In addition to these 33 vegetation plots within the Park, two groups of three plots were also established along transects within Kahauale`a, just north of the Park boundary (Fig. 27).

Ground Cover - Ninety-six vascular plant species were observed within the vegetation plots when they were established in 1994; the cover of bryophytes, litter, soil, and rock was also measured. Despite the relatively large number of species observed, the ground cover of these pig-disturbed areas was very sparse. Most plots had a high cover of litter (averaging 70.5%) and exposed soil (8.0%). On average, only 21% of the ground cover was composed of living plants; ferns had the most cover of any plant group. Thirty-one fern species were found in vegetation plots, and all but three of these were native plants. The fern with the most cover was the tree fern hāpu`u pulu; this species had an average of 6.6% cover, and pig-damaged tree fern trunk had an additional 0.5% cover in plots. Second in abundance was the alien scaly swordfern, which had an average ground cover of 2.4%. Uluhe was common in the study area, but was not an important component of plot vegetation, averaging only 0.3%. `Ōhi`a saplings and small trees were the most often encountered woody plants within plots; these had an average cover of 1.2%. Pū`ahanui (*Broussaisia arguta*) and waiawi were also common, with 0.8 and 0.6% average cover, respectively. The most abundant grass in disturbed plots was the alien Hilo grass, which had 1.2% cover in the average plot. Bryophytes had noticeable ground cover as terrestrial plants (2.0%) and as epiphytes on logs and tree bases (1.4%). Table 6 lists all species with >0.3% average cover in the 39 disturbed plots in 1994.

A subset of 26 pig-disturbed plots was remonitored approximately 1.5 years after establishment, and cover values in 1994 and 1996 were compared. The six Kahauale`a plots were re-examined, as well as 20 of the Park plots (Table 7). Within the group of 20 Park plots, significant decreases were noted in the cover of exposed soil ($t = 5.69$, $p = 0.0001$), pig-damaged tree fern trunk ($t = 3.21$, $p = 0.0046$), waiwi ($t = 2.77$, $p = 0.0121$), and pū`ahanui ($t = 2.05$, $p = 0.0510$). Increases in cover were noted for litter, uluhe, the native `ohe grass (*Isachne distichophylla*), pilo (*Coprosma menziesii*), alien scaly swordfern, and the invasive Hilo grass. Pilo increased from 0.3 to 0.5% in the 20 Park plots, a change that was nearly significant ($t = 1.95$, $p = 0.0662$). Hilo grass nearly tripled in cover over the 1.5 year period in the 20 Park plots without the Kahauale`a quads (1.6% to 4.5%), and this change was statistically significant ($t = 2.75$, $p = 0.0126$).

Table 6. Mean[1] ground cover (%) in 39 pig-disturbed plots (10 x 10m) in forests of the East Rift, Hawaii Volcanoes National Park and Kahauale`a in 1994.

Species[2]	Common Name	% Cover	Status[3]
Broussaisia arguta	pū`ahanui, kanawao	0.8	E
Bryophyte on logs	limu	2.0	E & I
Bryophyte terrestrial	limu	1.4	E & I
Cheirodendron trigynum	`ōlapa	0.3	E
Cibotium glaucum (Including live trunk)	hāpu`u pulu	6.6	E
Cibotium glaucum Pig-damaged trunk	hāpu`u pulu	0.5	E
Dicranopteris linearis	uluhe	0.4	I
Isachne distichophylla	`ohe	0.3	E
Litter		70.5	n/a
Melicope clusiifolia	alani	0.4	E
Metrosideros polymorpha	`ōhi`a	1.2	E
Nephrolepis exaltata	kupukupu	0.5	I
Nephrolepis multiflora	scaly swordfern	2.4	A
Paspalum conjugatum	Hilo grass	1.2	A
Pneumatopteris sandwicensis	hō`i`o kula	0.3	E
Psidium cattleianum	waiawi, strawberry guava	0.6	A
Soil		8.0	n/a

1 Mean cover derived by dividing total number of point-intercept hits for each species by the total number of available points in all plots (39).

2 Only species with ≥0.3% mean cover are reported.

3 E = Endemic, I = Indigenous, A = Alien

Table 7. Mean[1] ground cover (%) in 26 remonitored pig-disturbed plots (10 x 10m) in forests of the East Rift, Hawaii Volcanoes National Park (20 plots) and Kahauale`a (6 plots).

Species[2]	%Cover			
	Park 1994	Park 1996	Kahauale`a 1994	Kahauale`a 1996
Alyxia oliviformis Maile	0.02	0.4	0.3	0
Broussaisia arguta Pū`ahanui	0.5	0.3	2.1	0.9
Bryophyte, on logs Limu	2.1	3.2	1.8	2.9
Bryophyte, terrestrial Limu	1.2	1.3	0.4	1.3
Cheirodendron trigynum `Ōlapa	0.3	0.04	0.3	0.3
Cibotium glaucum Hāpu`u pulu (Including live trunk)	5.4	6.0	8.5	8.5
C. glaucum, pig damaged Hāpu`u pulu	0.6	0.1	0.4	0.3
Coprosma menziesii Pilo	0.3	0.5	0	0
Dicranopteris linearis Uluhe	0.7	1.2	0.1	0.1
Elaphoglossum crassifolium `Ekaha	0.2	0.2	0	0.1
Freycinetia arborea `Ie`ie	0.02	0	0.3	0.7
Isachne distichophylla `Ohe	0.5	0.9	0	0
Litter	68.7	68.9	65.3	74.6
Machaerina mariscoides `Uki	0.2	0.2	0	0
Melicope clusiifolia Alani	0.1	0.3	0.5	0.3
Metrosideros polymorpha `Ōhi`a	0.9	0.9	0.6	0.9
Microlepia strigosa Palapalai	0.4	0.3	0	0
Myrica faya Firetree	0.3	0.2	0	0
Nephrolepis exaltata Kupukupu	1.0	2.3	0	0
Nephrolepis multiflora Scaly swordfern	2.5	4.0	1.7	1.5
Paspalum conjugatum Hilo grass	1.6	4.5	0.5	0.5

Table 7 (Cont'd). Mean[1] ground cover (%) in 26 remonitored pig-disturbed plots (10 x 10m) in forests of the East Rift, Hawaii Volcanoes National Park (20 plots) and Kahauale`a (6 plots).

Species[2]	%Cover Park 1994	Park 1996	Kahauale`a 1994	Kahauale`a 1996
Perrottetia sandwicensis Olomea	0.04	0.02	0	0.9
Pneumatopteris sandwicensis Hō`i`o kula	0	0	1.8	1.4
Psidium cattleianum Waiawi, strawberry guava	1.0	0.5	0	0
Psychotria hawaiiensis Kōpiko	0.1	0.1	0.3	0.4
Sadleria pallida `Ama`u	0.2	0	0.3	0.2
Setaria gracilis Foxtail grass	0.3	0.4	0	0
Soil	9.2	1.4	13.5	3.1

1 Mean cover derived by dividing total number of point-intercept hits for each species by the total number of available points in all plots of group.
2 Only species with ≥0.2% mean ground cover are reported.

Within the six Kahauale`a plots alone, exposed soil also decreased as a percentage of ground cover (from 13.5% to 3.1%), and the change was statistically significant ($t = 4.71$, $p = 0.0053$). Smaller decreases in cover were noted for pū`ahanui, pig-damaged tree fern trunk, scaly swordfern, and ho`i`o kula. Increases in cover were observed in Kahauale`a for bryophytes on logs, terrestrial bryophytes, `ie`ie (*Freycinetia arborea*), litter, and the native tree olomea (*Perrottetia sandwicensis*). Only the changes in epiphytic bryophytes ($t = 2.61$, $p = 0.0477$) and litter ($t = 10.7$, $p = 0.0002$) appeared to be significant.

Woody Plant Density - Forests of the East Rift were relatively low in woody species diversity. `Ōhi`a lehua was the most abundant tree species in pig-disturbed plots, and the average plot had `ōhi`a trees of several diameter classes, as well as a large number of saplings (Table 8, Table 9). Alani (*Melicope clusiifolia*) ws the next most common native tree species, with a high mean plot density of young plants less than 1 m in height. The mean number of saplings of other native woody species was very low in pig-disturbed plots; apart from `ōhi`a and alani, only waiawi and `ōhelo kau la`au (*Vaccinium calycinum*) had a mean greater than 1 for young plants <1 cm diameter in either of two height categories. Few tree species other than `ōhi`a were represented among the larger diameter trees in disturbed plots. `Ōlapahad a mean of approximately 1 tree in each of the first three diameter classes >1 cm, and a very low mean of 0.1 tree in the 20-40 cm diameter class (Table 9). Only six other species had representatives in three or more diameter classes >1 cm; these were `a`ali`i (*Dodonaea viscosa*), manono (*Hedyotis terminalis*), alani, firetree, kōlea (*Myrsine lessertiana*), and kōpiko (*Psychotria hawaiiensis*). Means were extremely low for all these species in diameter classes above 1-5 cm.

Table 8. Mean density (no./100 m^2) of woody plant species in all size classes >10 cm height within 39 pig-disturbed vegetation plots in forests of the East Rift, Hawaii Volcanoes National Park and Kahauale`a.

Species	Common Name	Mean # Plants	SD[1]
Alyxia oliviformis	maile	3.7	33.5
Antidesma platyphyllum	hame	0.03	0.3
Broussaisia arguta	pū`ahanui	2.2	20.7
Cheirodendron trigynum	`ōlapa	3.6	17.0
Clermontia hawaiiensis	`ōhā kēpau	0.03	0.3
Clermontia parviflora	`ōhā	0.5	3.1
Coprosma menziesii	pilo	1.1	8.2
Coprosma ochracea	pilo	0.8	5.4
Coprosma sp.	pilo	0.6	5.1
Cordyline fruticosa	ti, ki	0.1	0.8
Cyrtandra platyphylla	`ilihia	0.3	3.0
Dodonaea viscosa	`a`ali`i	0.2	1.3
Freycinetia arborea	`ie`ie	0.6	4.4
Hedyotis terminalis	manono	0.5	3.8
Ilex anomala	kāwa`u	0.5	2.4
Melicope clusiifolia	alani	13.5	120.5
Melicope radiata	alani	0.2	1.2
Melicope sp.	alani	0.2	2.1
Metrosideros polymorpha	`ōhi`a	26.3	108.8
Myrica faya	faya, firetree	1.1	5.6
Myrsine lessertiana	kōlea	1.5	8.9
Myrsine sandwicensis	kōlea lau li`i	0.1	0.8
Passiflora edulisl	liliko`i	0.03	0.3
Perrottetia sandwicensis	olomea	0.1	0.7
Pipturus albidus	mamaki	0.1	0.7
Psidium cattleianum	waiawi	10.9	78.8
Psychotria hawaiiensis	kōpiko	3.3	18.8
Rubus rosifolius	thimbleberry	0.9	10.9
Stachytarpheta dichotima	vervain	0.3	2.0
Styphelia tameiameiae	pukiawe	0.03	0.3
Tetraplasandra hawaiensis	`ohe mauka	0.03	0.3
Vaccinium calycinum	`ōhelo kau la`au	4.0	32.9
Wikstroemia sandwicensis	`akia	0.4	3.0

[1] SD=Standard Deviation

Table 9. Mean density (no./100 m^2) in height and diameter classes of selected woody plant species within 39 pig-disturbed vegetation plots in forests of the East Rift, Hawaii Volcanoes National Park and Kahauale`a (seedlings <10 cm in height excluded).

Species			Basal Diameter (cm)				
	<1 Ht<1 m	**<1 Ht≥1m**	**1-5**	**>5-10**	**>10-20**	**>20-40**	**>40-80**
Cheirodendron trigynum	0.6	0	0.9	1.0	1.0	0.1	0
Coprosma menziesii	0.5	0.3	0.5	0.03	0	0	0
Dodonaea viscosa	0	0	0.1	0.05	0.03	0	0
Hedyotis terminalis	0.2	0	0.3	0.03	0.03	0	0
Ilex anomala	0.2	0	0.2	0.05	0	0	0
Melicope clusiifolia	11.3	0.1	1.8	0.3	0.1	0	0
Melicope radiata	0.1	0	0.03	0.03	0	0	0
Metrosideros polymorpha	9.2	0.1	6.2	3.8	3.4	2.8	0.8
Myrica faya	0.2	0.05	0.3	0.1	0.4	0.03	0
Myrsine lessertiana	0.8	0.03	0.5	0.05	0.05	0	0
Psidium cattleianum	5.7	0.1	4.8	0.3	0	0	0
Psychotria hawaiiensis	0.7	0	1.5	0.3	0.6	0.1	0
Vaccinium calycinum	3.7	0.1	0.2	0	0	0	0
Wikstroemia sandwicensis	0.1	0	0.3	0.1	0	0	0

Few changes in woody plant density were observed in the 26 plots that were remonitored after 1.5 years. Only trees and shrubs in the two smallest diameter classes (<1 cm and 1-5 cm) were recounted; for the smallest diameter class, terrestrial plants were distinguished from those rooted epiphytically on logs, tree trunks, or tree ferns. Within the 20 remonitored plots in the Park study area, a significant increase was observed in terrestrial `ōlapa <1 cm diameter (t=2.46, p=0.0235). Modest increases were also noted in the terrestrial <1 cm diameter category for maile (*Alyxia oliviformis*), *Cyrtandra* spp., alani, `ōhi`a, and `ōhelo kau la`au (Table 10). A significant decrease was noted in `ōhi`a of the 1-5 cm diameter class (t=2.54, p=0.210). This and smaller decreases in other species for this size class (i.e. `ōlapa, firetree, waiawi) are likely due to tree growth into the larger diameter class (>5-10 cm) that was not remonitored.

The six Kahauale`a plots showed even less change than the 20 remonitored Park vegetation plots. Small increases were noted in terrestrial alani of the <1 cm diameter class and in epiphytic `ōhi`a <1 cm, and decreases in mean density were observed for terrestrial kōpiko and epiphytic `ōhelo (Table 10). No changes in density within the Kahauale`a plots appeared to be significant.

Tree Ferns - Tree ferns or hāpu`u were also counted in 39 pig disturbed vegetation plots in 1994, using the same trunk height or length categories that were used in the more widespread system of count plots along transects. The mean number of tree ferns of any height (excluding very small individuals with no trunk) was 26.2/100 m^2, considerably lower than the mean density of tree ferns found on systematic plots along transects reported earlier (38.1). The height class of small individuals <0.5 tall was best represented in disturbed plots, with a mean of 11.0. The average number of tree ferns in the 0.5-1m height class was 4.5. Tree ferns in the >1-2 m class averaged 7.6/plot, but taller ferns >2 m were uncommon, with a plot mean of only 3.1. In addition to healthy tree ferns, approximately 80% of plots had a low number of ferns that showed signs of trunks being ripped open and fed upon by pigs. The number of pig-damaged tree ferns per plot ranged from 0 to 6, but averaged 2.5 in all 39 disturbed vegetation plots. The size class most often targeted by pigs was that of ferns >1-2 m in height. The mean number of damaged ferns in this class (1.0/plot) was almost double the observed mean in any other class (<0.5 m, 0.4; 0.5-1 m, 0.6; >2m, 0.5).

Tree ferns were recounted in 1996, and increases in overall density were noted in both the 20 remonitored Park plots and those of Kahauale`a. For both groups of plots increases were primarily in the young tree fern category of <0.5 m (Table 11). Slight decreases were noted in the >1-2 m height class in both areas, but this change may have been due to ferns entering the next tallest class, which showed a gain in numbers of tall tree ferns. Comparing differences in tree fern density from 1994 to 1996 with paired t-tests, no changes were significant for any size class in either the 20 remonitored Park plots or the 6 Kahauale`a plots. When remonitored Park plots were grouped by geographical position in the study area (i.e. lower area near fence line, central area west of 1840 flow, and upper area near Makaopuhi and Nāpau Craters, see Fig. 27), a different pattern was observed in the three groups of disturbed plots. The mean number of tree ferns stayed the same in upper plots, and an increase in tree fern numbers was observed in lower plots near the fence line. A significant decrease in tree fern density was noted in nine centrally-located plots near transects 1, 1A, and 2 (t=2.58, p=0.0327), where the mean number of tree ferns of any size (excluding those with no trunk) declined from 22.7 to 19.6/100 m^2. In this group of plots, decreases were observed in all height classes of tree ferns with trunks.

Table 10. Mean density (no./100m^2) of selected woody species in small diameter classes (excluding plants <10 cm in height) in 26 remonitored pig-disturbed plots in forests of the East Rift, Hawaii Volcanoes National Park (20 plots) and Kahauale`a (6 plots).

Species	Diameter (cm)	Park 1994	Park 1996	Kahauale`a 1994	Kahauale`a 1996
Alyxia	<1 ter [1]	5.40	5.70	0.67	1.00
oliviformis	<1 epi [1]	0.45	0.45	0	0
	1-5	0.35	0.25	0.83	1.00
Cheirodendron	<1 ter	0.15	0.70*	0.33	0.33
trigynum	<1 epi	0.30	0.20	1.00	0.33
	1-5	0.65	0.50	0.67	0.67
Clermontia	<1 ter	0.15	0.05	0.17	0.17
parviflora	<1 epi	0.10	0.05	0.50	0.33
	1-5	0	0.20	0.33	0.17
Coprosma	<1 ter	3.00	2.35	0	0.17
spp.	<1 epi	0.15	0.10	0	0
	1-5	1.35	1.30	0	0
Cyrtandra	<1 ter	0.05	0.40	0	0
spp.	<1 epi	0	0	0	0
	1-5	0.30	0.50	0.17	0.17
Melicope	<1 ter	5.30	5.85	8.00	10.50
spp.	<1 epi	0.40	0.55	1.17	0.83
	1-5	0.60	0.70	2.33	1.66
Metrosideros	<1 ter	1.25	2.80	0.17	0.17
polymorpha [2]	<1 epi	6.10	7.50	1.17	2.00
	1-5	3.83	1.55*	0.83	0.33
Myrica	<1 ter	0.50	0.40	0	0
faya	<1 epi	0	0.50	0	0
	1-5	0.65	0.45	0	0
Myrsine	<1 ter	1.05	0.70	0	0.17
spp.	<1 epi	0.25	0.15	0	0.17
	1-5	0.80	0.75	0	0
Psidium	<1 ter [1]	7.10	4.00	0.17	0
cattleianum [2]	<1 epi [1]	0	0	0.33	0.17
	1-5	3.22	2.11	0	0

Table 10 (Continued). Mean density (no./100m²) of selected woody species in small diameter classes (excluding plants <10 cm in height) in 26 remonitored pig-disturbed plots in forests of the East Rift, Hawaii Volcanoes National Park (20 plots) and Kahauale`a (6 plots).

Species	Diameter (cm)	Park 1994	Park 1996	Kahauale`a 1994	Kahauale`a 1996
Psychotria	<1 ter	1.00	0.70	1.17	0.50
hawaiiensis	<1 epi	0	0	0.33	0.17
	1-5	0.95	1.10	6.00	5.83
Vaccinium	<1 ter	0.60	0.85	1.33	1.33
calycinum	<1 epi	1.90	1.40	4.00	2.17
	1-5	0.05	0	0	0

* Significantly different at or above the 95% confidence level.

[1] ter=terrestrial; epi=epiphytic

[2] *Metrosideros polymorpha* and *Psidium cattleianum* in 1-5 cm class remonitored in only 18 Park vegetation plots.

Soil Depth

Soil depth was measured along the three longest primary transects of the Park study area above the barrier fence to provide information on the substrates at different geographical areas and to help explain observed differences in vegetation. Soil depths were very similar on transect 2 in the western part of the study area (mean depth=26.4 cm) and transect 3A beyond the pig barrier fence to the east (mean depth=26.5 cm). Greatest soil depth (mean=30.8 cm) was measured on transect 3, located between transects 2 and 3A (Fig. 1). An analysis of variance and mean separation test (Waller-Duncan k-ratio t-test) indicated that the mean soil depth of transect 3 was significantly greater than that of transects 2 and 3A ($F=7.11$, $p=0.0009$). Holcomb (1987) mapped the areas on both sides of the 1840 lava flow as the same unit of Kāne Nui o Hamo flows with a range in age of 500 to 750 years BP. Therefore, soils in this volcanically young area overlay adjacent flows that may vary as much as 250 years in age.

Soil depths in the upper half of each of the three primary transects were compared with those on the lower half of the same transect. Little change in mean soil depth was noted along the western transect 2, where the mean soil depth was 27.7 cm on the upper half and 25.1 cm on the lower half. However, soils on both transects 3 and 3A were significantly deeper in the upper half (33.5 and 28.5 cm) than in the lower half of the transects (28.1 and 24.4 cm) (transect 3 $t=2.77$, $p=0.0075$; transect 3A $t=1.97$, $p=0.0509$). This greater depth along the upper part of easternmost transects may reflect a deeper accumulation of ash and tephra with proximity to Pu`u `Ō`ō, the site of vigorous lava fountaining and tephra production from 1983 to 1986.

Despite the observation that tree ferns varied in abundance on the upper versus the lower halves of at least two of the long transects, there was no strong correlation between soil depths and tree fern densities ($R^2=0.275$).

Table 11. Density (no./100 m^2) of tree ferns in five trunk height classes within remonitored pig-disturbed plots of East Rift rain forests in Hawaii Volcanoes National Park and Kahauale`a.

Height	Park 1994	Park 1996	Kahauale`a 1994	Kahauale`a 1996
No trunk	3.5	5.8	5.2	3.2
<0.5 m	11.5	13.6	13.5	21.0
0.5-1 m	4.8	3.7	3.3	3.8
>1-2 m	6.3	5.8	8.2	7.2
>2 m	2.1	2.3	1.7	3.0
Total (with trunk)	24.7	25.3	26.7	34.0

Feral Pig Activity

Frequency of feral pig sign was relatively low along Park transects at monitoring periods throughout the study from June 1993 to January 1996 (Fig. 28). At the first activity monitoring period before staff hunting began (June 1993), frequency of fresh pig sign was <1% on transect 2, 2.5% on transect 3, and only 1.3% on transect 3A. Greatest pig activity frequencies of the study were found on Park transects during December 1993, three months after the commencement of snaring by Park managers. At this time period, frequency of fresh pig sign was 7.5% on transect 2, an extremely high 39.6% on transect 3, and 4.2% on transect 3A east of the end of the barrier fence (Table 12). After June 1994, no fresh pig activity was detected on the western transects 1 or 2A, and activity was noted at low frequency (2.5%) during only one additional period on transect 2. A relatively low level of fresh pig activity continued to be evident on the easternmost transects 3 and 3A throughout 1994 and 1995. Transect 3 had the highest average frequency of fresh pig sign (6.4%) of all the Park transects monitored over the 2.5-year period.

During the periods when fresh or intermediate pig activity was detected along transect 1, which is also the trail between the Kalapana Trail junction and Makaopuhi Crater edge, this activity was concentrated in the central part of the trail away from the edge of the lava and below the trail skirting Makaopuhi Crater. Combining all the monitoring periods, pig activity was scattered throughout the length of the long primary transect 2, with some concentration of activity in the central portion of the transect and in the last 200 m near the barrier fence (Fig. 29). On transect 3, fresh and intermediate pig activity was most pronounced in a 450 m stretch just southeast of Pua`i`ālua Crater and in the last 800 m nearest the barrier fence. Pig activity on transect 3A, to the east of the end of the barrier fence, was most often seen in the lower half of the transect, but fresh and intermediate sign was also sparingly distributed in the upper half.

Table 12. Frequency of fresh pig activity along transects in forests of the East Rift, Hawaii Volcanoes National Park, June 1993-January 1996.

Monitoring Period-Date	Transect 1	2	2A	3	3A	Park Mean
(1) 06/1993	nd[1]	0.8%	0	2.5%	1.3%	1.3%
(2) 09/1993	nd	nd	1.7%	nd	3.8%	3.1%
(3) 12/1993	nd	7.5%	0	39.6%	4.2%	14.6%
(4) 03/1994	2.5%	1.7%	5.0%	3.3%	0	2.2%
(5) 06/1994	nd	0	0	0.4%	0.8%	0.4%
(6) 09/1994	0	0	0	6.3%	1.7%	2.0%
(7) 12/1994	0	0	0	2.1%	0	0.5%
(8) 03/1995	0	2.5%	0	0.4%	0.4%	0.8%
(9) 06/1995	0	0	0	2.9%	1.7%	1.1%
(10) 01/1996	0	0	0	0	8.8%	2.2%
Mean all periods	0.4%	1.4%	0.7%	6.4%	2.3%	2.3%

[1] nd = no data

Compared with Park transects, feral pig activity was detected with much greater frequency on the four short transects of Kahauale`a, just north of the Park boundary (Fig. 28). This difference in mean frequency of fresh pig sign (arcsin transformed) was highly significant ($t=5.93$, $p=0.0001$). No organized pig control took place in Kahauale`a during the course of the study, and the level of public hunting is relatively low because of the distance of the site from road access (>7 km). Mean pig activity frequency for the four Kahauale`a combined ranged from a high of 20.8% in December 1994 to a low of 6.3% at the end of the study in January 1996, but there was no clear trend of increase or decrease throughout the study. High frequencies of fresh pig sign >25% were observed along transects 8 and 11 during several sampling periods (Table 13), and the overall mean pig activity frequency for Kahauale`a transects during all sampling periods was 12.4%. Feral pig activity was distributed throughout three of the Kahauale`a transects during the 2.5 years of monitoring, although there was some concentration of activity to the interior of the forest at the transect ends farthest from the boundary with the Park (Fig. 30).

Using a model for all fresh pig sign developed in a variety of forest habitats in Hawai`i (Anderson and Stone 1994), the estimated density of feral pigs in the East Rift study area of the Park was calculated as 2.4 pigs/km^2 for the entire 2.5-year monitoring study. For all Park transects combined, the feral pig density was highest during the third sampling period of December 1993 (5.7 pigs/km^2), and declined to a low of 1.2 pigs/km^2 in June 1994.

Table 13. Frequency of fresh pig activity along Kahauale`a transects adjacent to Hawaii Volcanoes National Park, June 1993-January 1996.

Monitoring Period-Date	Transect Kahauale`a 8	9	10	11	Mean
(1) 06/1993	nd[1]	12.5%	6.8%	20.3%	13.6%
(2) 09/1993	nd	nd	nd	nd	nd
(3) 12/1993	16.7%	1.7%	4.5%	10.9%	7.3%
(4) 03/1994	16.7%	11.7%	0	4.7%	9.4%
(5) 06/1994	31.7%	14.2%	6.8%	4.7%	14.6%
(6) 09/1994	21.7%	15.8%	4.5%	26.6%	17.7%
(7) 12/1994	46.7%	4.2%	0	42.2%	20.8%
(8) 03/1995	13.3%	12.5%	2.3%	0	8.3%
(9) 06/1995	6.7%	3.3%	4.5%	35.9%	11.5%
(10) 01/1996	25.0%	1.7%	2.3%	0	6.3%
Mean all periods	22.3%	8.6%	3.5%	16.1%	12.4%

[1] nd = no data

Pig activity data collected during the three last sampling periods resulted in pig density estimates of approximately 1.5-2.3 pig/km^2 (Table 14). Declines to zero (no detectable pigs) were observed in the western transects (1,2, and 2A), but transect 3 near the end of the barrier fence maintained a density of approximately 2 pigs/km^2 for two years of the study (June 1993 to June 1995). Estimated pig densities did not decline along the easternmost transect 3A, beyond the open end of the barrier fence, and the population density for the final monitoring period of January 1996 on this transect was similar to the mean density of pigs calculated for the unmanaged forests of Kahauale`a.

During the same 2.5 years of pig activity monitoring, the pig population density in the adjacent, unmanaged Kahauale`a forest was estimated as 5.3 pigs/km$^2$, using all sampling periods. Estimated pig densities (detectable above 0) for individual quarterly samplings on the Kahauale`a transects ranged from a low of 2.1 pigs/km^2 to a high of 9.0 pigs/km^2. While estimated pig densities fluctuated on the Kahauale`a transects, and several sampling periods had zero pigs detected on individual transects, no pattern of decline in density of feral pigs was observed in this area during the study.

Table 14. Estimated feral pig density (#/km²) calculated from all fresh pig sign[1] along five transects in Hawaii Volcanoes National Park and four transects in adjacent forests of Kahauale`a, 1993-1996.

Sample	Transect					Park	Transect				Kahauale`a
Period	1	2	2A	3	3A	Mean	8	9	10	11	Mean
06/93	nd[2]	1.5	0	2.5	1.8	1.9	nd	5.1	3.9	6.3	5.5
09/93	nd	nd	2.1	nd	2.9	2.7	nd	nd	nd	nd	nd
12/93	nd	4.0	0	8.4	3.1	5.7	5.8	2.1	3.2	4.8	4.1
03/94	2.5	2.1	3.4	2.8	0	2.3	5.8	4.9	0	3.3	4.6
06/94	nd	0	0	1.2	1.5	1.2	7.7	5.4	3.9	3.3	5.7
09/94	0	0	0	3.7	2.1	2.3	6.5	5.6	3.3	7.1	6.3
12/94	0	0	0	2.3	0	1.3	9.0	3.1	0	8.7	6.8
03/95	0	2.5	0	1.2	1.2	1.5	5.2	5.1	2.4	0	4.3
06/95	0	0	0	2.6	2.1	1.7	3.8	2.8	3.2	8.1	5.1
01/96	0	0	0	0	4.3	2.3	6.9	2.1	2.4	0	3.8

[1] Anderson and Stone 1994: Y=0.28 + 13.85 X, where X=frequency of fresh pig activity, arcsin transformed.

[2] nd=no data

DISCUSSION

The attempt at reduction of the feral pig population to negligible levels behind a barrier fence is a notable departure from the Park's typical goal of exclusionary fencing and eradication of animals (Stone and Loope 1987). Barrier fences were used along the Park's boundary above 2,135 m (7,000 ft) elevation to reduce the ingress of feral goats, sheep, and mouflon, but this method of partial exclusion was not very successful, and Park managers enclosed the vegetated portions of the alpine and subalpine zones in 1998 (T. Tunison pers. comm. 1998). All other pig control units within the Park are protected by fenced exclosures, and recovery of native vegetation from pig damage is progressing in areas where monitoring has been carried out (Pratt and Abbott 1997, Pratt and Abbott in prep.). The vegetation component of the East Rift monitoring project was intended to provide a baseline to allow both short-term and long-term future evaluation of recovery or change due to the control of feral animals and continued management within the SEA.

Alien Plants

Alien plant species are an important component of the flora of the low- to middle-elevation forests of the Park's East Rift and are one of the primary threats to the native ecosystems of Hawaii Volcanoes (National Park Service 1996), as well as to other natural areas in Hawai`i (U. S. Congress, Office of Technology Assessment 1993; Loope 1992). While alien plants have a number of negative effects on natural vegetation, one of their most serious impacts is the displacement of native plants; this effect is typically accelerated by disturbance from feral ungulates (Smith 1985). The nearly 50 species of alien plants found along transects likely represent most of the alien flora of the study area, although a few additional herbaceous weedy species have been noted during previous studies in nearby forests and lava flows (Cuddihy *et al.* 1986, Higashino and Stone 1982).

The length of time that these alien plants have been in the study area is unknown, but more than 30 of the same species were found within five 1-ha study sites in East Rift Forests in 1983 (Cuddihy *et al.* 1986). In a botanical survey of the Kalapana Extension approximately 40 years ago, only 16 of the 48 study area alien plants were noted as present in what is now the eastern section of the Park; other alien species were confined to the coastal lowlands (Stone 1959). Currently invasive plants such as Hilo grass, waiwi, and lantana were already established in the study area by 1959, but firetree, melastomes (*Melastoma candidum, Tibouchina herbacea*), and several grass species were not noted in the older survey. It is likely that more than half of the alien plants currently found within the study area have invaded the Park's East Rift forests in the last few decades.

Most of the alien plants of the Park's East Rift forests are relatively innocuous species, and these are largely opportunistic generalists favored by disturbance (Wester 1992). Of the eight most invasive East Rift weeds, five are currently widespread and abundant, and three others have shown their disruptive capability elsewhere. These potentially disruptive alien plant species make up a larger percentage of the non-native flora in East Rift forests than is commonly seen elsewhere in Hawai`i's natural areas, where the seriously invasive component is usually less than 10% (Loope 1992).

Grasses - Of the ten alien grass species found along East Rift transects, only two species occurred with a frequency >10% in 1992-94. Broomsedge is a large bunchgrass more typical of dry to mesic open areas (Smith 1985) that rarely achieves high cover in forest vegetation (Mueller-Dombois 1973). The dramatic decrease in frequency of this species between 1988 and 1992 is probably explained by the continued recovery of the forest canopy following the cessation of lava fountaining and tephra outfall in 1986. Although it is a relatively recent arrival in the Park and was apparently not present in the eastern part of the Park in 1959 (Stone 1959), this grass is now a major component of dry open woodlands and coastal lowlands to the south and west of the study area. The distribution of the grass in the East Rift study site 1992-94 suggests that artificial disturbance along trails and nearness to sunny kīpuka edges and exposed summits are factors promoting the establishment of this wind-dispersed grass, which will likely remain a small component of East Rift open forests. The grass is unlikely to pose a significant threat to the forests, unless wildfires occur. The presence of broomsedge and other flammable introduced grasses makes native vegetation more vulnerable to damage from fires, and the fire-tolerant grass typically increases its cover following fire (Tunison *et al.* 1994, Hughes *et al.* 1991).

Hilo grass is a more serious threat to East Rift rain forests. The grass was nearly ubiquitous throughout the study area, and relatively high cover values (5-25%) were noted below 760 m (2500 ft) elevation. In contrast to broomsedge, Hilo grass showed a pronounced intensification in the period between surveys. Past pig activity may be responsible for the observed increase in Hilo grass throughout the study area, as pigs have been identified as agents of Hilo grass intensification and dispersal elsewhere in Hawai`i (Loope *et al.* 1992, Smith 1985). Short-term monitoring of pig-dug vegetation plots in East Rift forests indicated that this grass is likely to continue to increase its cover in formerly disturbed areas. Although there is not currently a dense layer of Hilo grass in the study area, the potential for continued expansion and intensification is a cause for concern. In Kīpahulu Valley of Haleakalā National Park on Maui, Hilo grass spread upslope rather quickly in areas damaged by feral pigs (Yoshinaga 1980). Even after pigs had been removed for more than 10 years, Hilo grass persisted at high levels in koa forest and prevented native woody plant regeneration (Anderson *et al.* 1992). Although Hilo grass can be controlled through the use of herbicides (Santos, unpublished data), such chemical control has not been attempted on a large scale within Hawaii Volcanoes National Park, and biological control has not been investigated for this species (Smith 1985). Hilo grass is one of the five worst weeds in the East Rift SEA, and it will likely require future control efforts if the rain forest is to be restored after pig removal.

Trees and Shrubs - Of the 14 woody alien plant species detected along East Rift transects in the Park, four offer the greatest threat to the integrity of the rain forests. Strawberry guava or waiwi is the most widespread invasive tree in East Rift forests. Because it is perhaps the "worst pest in Hawai`i's rain forests" (Smith 1985), and has invaded other Park rain forests at elevations above 1,220 m (4,000 ft) elevation (Pratt and Abbott in prep.), the abundance of this species in the East Rift SEA is an indication that active management is needed. In Kīpahulu Valley, Maui, strawberry guava has formed nearly impenetrable thickets at 460-760 m (1,500-2,500 ft) elevation, and this displacement of natural vegetation has threatened a number of rare native species (Loope *et al.* 1992). The upper elevation of the heavily invaded area on Maui is comparable with the elevation of the lower half of the East Rift study area.

The ability of strawberry guava to quickly dominate native forests is due to its habit of reproducing by both seed and vegetative suckers. In a study of strawberry guava recruitment on the Kalapana Trail, near the current study area, Huenneke and Vitousek (1990) found that strawberry guava was hardly producing suckers, and more than 90% of the young plants were seedlings; this lack of clonal behavior in East Rift rain forests was the reverse of the trend observed at a site near Stainback Highway. In the same study, the growth rate of strawberry guava near the Kalapana Trail was found to be less than half that measured in higher elevation rain forest near Thurston Lava Tube. The low growth rate of strawberry guava observed by Huenneke and Vitousek on the East Rift may be related to the tree's intolerance to sulfur dioxide and other volcanic fumes. Strawberry guava appears to be susceptible to volcanic fumes, as defoliation and dieback were noted during a 1988 extensive survey of East Rift forests (Anderson *et al.* unpublished a), as well as during the current survey. In 1992-94, strawberry guava was less common on easternmost transects subjected to the greatest cinder-fall and closest to the source of volcanic fumes from Pu`u `Ō`ō.

The lack of spread and intensification of strawberry guava between the current and past surveys is encouraging and may imply that Park managers have a window of opportunity to control the species that may pass when the current eruption ceases. Huenneke and Vitousek (1990) noted that feral pig control alone was not likely to slow the plant's spread, as strawbery guava could generate or regenerate dense stands very quickly even in the absence of ground disturbance. However, one finding of the Huenneke and Vitousek study did provide hope for the success of local management efforts; they found few viable guava seeds in the soil of their study sites, and speculated that seeds either germinated quickly or died. Strawberry guava is widespread in lowland forests east of the study area, but this reservoir of seed-dispersing plants is now separated from Park forests by a large expanse of recent lava. Because of its long residence in Hawai`i, future distributional increases are not considered likely, although the species may intensify in areas already occupied (Jacobi and Warshauer 1992). A search is underway for effective biocontrol agents for strawberry guava, but this is typically a long-term project (Ellshoff *et al.* 1995). The Forest Service has one potential strawberry guava biocontrol agent undergoing host specificity testing at the Park quarantine facility, and three more insects may be tested in the near future (S.Hight, pers. comm. 1999)

Firetree, long considered to be one of the most invasive plants within Hawaii Volcanoes National Park (Smathers and Gardner 1979), was the second-most frequent invasive woody plant found in East Rift forests during the 1992-94 survey. Like strawberry guava, no increase in frequency was detected between the current and previous survey. Elsewhere in the Park, firetree has continued to expand its distribution over the last decade, and the species currently covers more than 15,000 ha within the Park (Camrath *et al.* in press) Firetree is not generally considered to be a successful invader of closed rain forests (Vitousek and Walker 1989, Lipp 1994); its nitrogen-fixing capability does not give the tree a competitive advantage in older, more nutrient-rich soils, and dense shade reduces the germination rate of firetree seeds. The relatively dense `ōhi`a forests of the upper study area may not be in imminent danger of rapid firetree invasion. However, the proximity of densely infested woodlands near the Kalapana Trail and the abundance of firetrees at open sites on the western edge of the study area suggest that some level of management is necessary to prevent the eventual degradation of East Rift forests by firetree. The mesic forests on the western edge of the study area have been heavily invaded by firetree. Chemical control methods are known for the species (Cuddihy *et al.* 1991), and Park managers have been very successful in controlling firetree in several Special Ecological Areas and buffer zones (Tunison and Stone 1992). Research on potential biocontrol agents for firetree is continuing, and one promising leaf miner is currently in quarantine (S. Hight, pers. comm. 1999).

Yellow Himalayan raspberry was very infrequent on East Rift transects and appeared to be restricted to the upper elevations near Kāne Nui o Hamo. The failure of yellow Himalayan raspberry to greatly expand its range or frequency over the five years between sampling efforts may indicate that the species is an incipient invader within the study area. The raspberry apparently invaded the Park in the 1960s from the nearby University of Hawaii Agricultural Experiment Station, after the species was rejected as a desirable crop and plants were abandoned but not destroyed (Smith 1985). In the last 30 years, yellow raspberry has spread throughout the Park's `Ōla`a Forest (Anderson *et al.* unpublished b) near the site of original introduction, and is now considered one of the most invasive alien species in the Park (Tunison 1992). In `Ōla`a and nearby areas, yellow raspberry has invaded both disturbed and protected, closed forests. The lower elevational limit of this recently introduced species is not known with certainty. While yellow raspberry is not currently found at sites below 610 m (2,000 ft) elevation on the island (Gerrish *et al.* 1992), its potential range on windward Hawai`i likely extends lower. Based on elevation and rainfall patterns in its current habitat, Jacobi and Warshauer (1992) predicted that yellow Himalayan raspberry is capable of becoming far more widely distributed on Hawai`i Island, if such spread is not checked by control efforts. The predicted potential range includes most of the Park's East Rift rain forests. This alien species should be a priority for removal from the East Rift SEA, while such management is still possible. Even if the species is controlled on Kāne Nui o Hamo and prevented from immediate intensification within East Rift forests, future monitoring will be necessary to detect re-invasion of raspberry from bird-borne seeds.

The pronounced increase in frequency of cane tibouchina between surveys is an indication that this species, like yellow raspberry, has the potential to become much more widespread and abundant in East Rift rain forests. Cane tibouchina is a relatively recent introduction to the State, where it was first collected on Hawai`i Island only 20 years ago (Wagner *et al.* 1990). The shrub has spread quickly and is well established at many sites in Hilo and Puna Districts, including the Kahauale`a Natural Area Reserve and Kahauale`a Tract 22 adjacent to the Park's East Rift forests. While cane tibouchina may be controllable at present in the Park's East Rift SEA, its presence in State and private lands to the east and north means that a seed source for re-invasion will likely remain in close proximity to the Park. In a recent study of *Tibouchina herbacea* population ecology, Almasi (in press) found that seed dispersal was was much lower in forested sites than in open ones, and that most seeds fell within a meter of the parent plant. She also found that tibouchina seed germination was low in forested sites, particularly in the presence of leaf litter, and that seedling growth was reduced in habitats with canopy cover. These findings indicate that maintenance of closed forests and undisturbed ground cover may slow the spread and intensification of tibouchina and that long-distance seed dispersal may not be a serious threat in Park forests.

Scaly Swordfern - While not generally considered to be a highly invasive plant, scaly swordfern is a dominant or codominant ground cover in many lowland forests and woodlands in the Park. The large increase in frequency of this fern on transects between the two surveys may be an indication of its ability to become a greater component of ground cover in East Rift forests. This alien fern has high cover at many nearby `ōhi`a woodland sites in the submontane seasonal zone, where it carries fire into forests and recovers quickly, but does not exhibit an increase in cover after being burned (Tunison *et al.* 1995). The areas of greatest scaly swordfern abundance in the current survey were the easternmost transects below 760 m (2,500 ft) elevation directly downwind of Pu`u `Ō`ō; these sites received the greatest disturbance from cinder and tephra outfall during the period of high fountaining at the vent in 1983-86. At one site near the Kahauale`a boundary disturbed by heavy cinder-fall from Pu`u `Ō`ō, scaly swordfern went from being a minor component of ground cover (Cuddihy *et al.* 1986) to the most visibly abundant understory plant ten years later (pers. obs.). The fern is thought to be a relatively recent introduction to Hawai`i; Wagner (1950) reported that it was first collected on O`ahu in 1923 and remained "very localized in the islands." Stone (1959) listed several localities in the Kalapana Extension from the coast to Nāpau Crater that supported scaly swordfern as early as 1929, but he gave no assessment of the abundance of the fern, which he considered indigenous at the time. By the mid-1960s, the fern was common in transition forests and on lava flows of the Park's Kalapana Extension, downslope of the East Rift Zone (Fosberg 1966). Scaly swordfern may not yet have achieved its potential range and abundance in forests of the East Rift. Only continued monitoring will reveal whether scaly swordfern retains its current high frequency and cover, or whether it will decrease as the rain forest canopy continues to recover.

Rare Plant Species and *Clermontia* Frequency

No listed endangered plant species were found during the current survey, and only two "species of concern" were observed along study area transects. The endangered pendent kihi fern *Adenophorus periens* may persist somewhere in the Park's East Rift forests, but the failure to relocate plants that were seen on the northeast facing slope of Kāne Nui o Hamo as recently as 1988 indicates that the species has undergone a decline in the study area and may have been lost from the Park. If the species is not rediscovered in the Park, the potential for re-introduction is great as long as a viable population remains in the forests of Kahauale`a. Forests with very similar structure and species composition to those of Kahauale`a are present on Kāne Nui o Hamo and both north and south of Nāpau Crater. The loss of this epiphytic fern species may have been due to natural causes associated with the fumes and canopy-disturbing cinder-fall from the nearby vent. Conditions more favorable to the fern may return after the cessation of the Pu`u `Ō`ō eruption.

Koli`i, a species of concern and former candidate endangered species, was restricted to Kāne Nui o Hamo in the study area, where it has persisted at least since the early 1980s. Even though comparisons with the previous survey indicated some decline in number over the last decade, the observed size class structure in 1993 suggests a relatively stable population with similar numbers of small and medium-sized plants and a lower number of large plants that are presumably near reproductive age. The high percentage of terrestrial plants and relatively large average size when compared with `Ōla`a plants in a population still vulnerable to feral pigs (Pratt and Abbott 1997) is evidence that the impact of pigs on the Kāne Nui o Hamo koli`i is currently minimal. The second "species of concern" found in the study area, *Anoectochilus sandvicensis*, has not been as successful as koli`i. This small terrestrial orchid was observed in very few sites, and plants were small and typically in poor condition. Management and augmentation or reintroduction may be required to ensure this plant's persistence in East Rift forests.

Other "species of concern" and former candidate endangered plant species previously known from the Park's East Rift forests were not found along transects in the current survey and have presumably undergone a reduction in distribution over the last few decades. At least two current or former "species of concern" were components of forests near Makaopuhi and Nāpau 50 years ago: the mint *Phyllostegia vestita* and the shrub `ānini (Fosberg 1966). Feral pigs may be responsible for the reduction in the abundance of the mint, as both *P. vestita* and the related *P. floribunda* (also a "species of concern") persist in East Rift craters inaccessible to pigs (Belfield 1998). `Ānini may have been lost from the area; feral pigs or the natural perturbation of lava flows may be responsible. Two other "species of concern" that were expected in the area, based on previous sightings nearby, were kilioe and `ahakea; neither was found during the 1992-94 East Rift survey. While recent volcanic activity can not be ruled out as a contributor to native plant species losses, it is likely that some of these rare species, as well as the pig-sensitive pala fern *Marattia douglasii* (found in a protected pit crater by Belfield in 1996 and in the pig-free kipuka by Higashino and Stone in 1982), would be more widespread in East Rift forests were it not for ongoing disturbance of the ground vegetation. The results of the current survey emphazise that East Rift forests have been experiencing a loss of native plant biodiversity and a reduction in the range of native species over the last several decades.

The dozen extant rare or sensitive species found along surveyed transects were concentrated in several forested portions of the study area. The eastern and northeastern slopes of Kāne Nui o Hamo supported relatively high numbers of the pig-sensitive *Clermontia parviflora* and *Cyrtandra* spp., as well as the only known East Rift population of koli`i. The tall `ōhi`a forest west and south of Nāpau Crater was also good habitat for *Clermontia parviflora* and contained examples of the terrestrial orchid *Anoectochilus sandvicensis* and the uncommon `ōhā kēpau and kāmakahala. Both these forests were characterized by a closed canopy of large `ōhi`a, a mix of native understory tree species, a distinct layer of tree ferns, and few highly invasive alien plant species. Both areas would be good candidates for focused management attention and intensive alien plant control. Two other areas also supported clusters of rare native plants, but were also more heavily invaded by alien plants. The slightly more open forests southeast of the 1840 flow provided habitat for *Clermontia parviflora*, *C. hawaiiensis*, kāmakahala, and hāme, an uncommon understory tree. The forests of the far southwestern portion of the study area, near the Nāulu access trail, were notable for supporting many large sandalwood trees. These lower-elevation forests of the East Rift will be a greater management challenge, because they are more heavily invaded by firetree, strawberry guava, and Hilo grass than are forests at higher elevation.

Clermontia frequencies were surprisingly high in East Rift forests; members of this lobelioid group are known to be palatable and vulnerable to feral pigs and are considered to be indicators of pig damage (Diong 1983, Stone and Loope 1987). Even though *Clermontia* plants were encountered with relatively high frequency overall in the study area, the impact of pig predation was indicated by the paucity of terrestrial plants and the low frequency with which large *Clermontia* were encountered. It is these large plants that are most often targeted and bark girdled by pigs. Such large plants are also most likely to bear flowers and fruits, and are therefore the most important size class for reproduction. Analysis of the subset of transects remonitored after 1.5 years revealed that terrestrial *Clermontia* were continuing to decline in frequency, while epiphytic plants of several size classes showed increases in frequency. These data indicate that pig predation was still impacting this vulnerable group of species, even two years after pig control efforts had begun. Thus, even if pig activity and density were reduced in the study area and vegetation recovery was progressing, the native plants most vulnerable to pigs were not being protected by the barrier fence and snaring efforts.

Density of Tree Ferns

Tree ferns or hāpu`u are one of the most important sources of food for feral pigs in rain forests of windward Hawai`i (Giffin 1978), and the ferns are therefore valuable indicator species for detecting site differences and vegetation recovery following pig population reduction. Feral pigs feed on tree ferns by ripping open the fibrous trunks and consuming the starchy core (Diong 1983); even when tree ferns survive after being fed upon, these decumbent, pig-damaged ferns may eventually die or be seriously weakened (Cooray and Mueller-Dombois 1981).

The overall density of tree ferns detected in East Rift forests of the study area (38.1/100 m^2) was slightly lower but similar to that of the pig-disturbed area east of the Pu`u Unit exclosure of `Ōla`a (45.4/100 $m^2$) and much lower than that of the area within the Pu`u Unit protected from pigs for eight years (60.8/100 m^2) (Pratt and Abbott in prep.). With one exception, all tree fern height classes showed lower densities in East Rift plots than in those outside the `Ōla`a Pu`u Unit. The one tree fern size class that had more individuals in East Rift plots was the 1-2 m group with a mean of 14 ferns/100 $m^2$ vs. 13 ferns/100 $m^2$ in unfenced `Ōla`a. A greater density of tree ferns is expected in `Ōla`a, as the hāpu`u/`ōhi`a vegetation type and deep ash soil there support the greatest abundance of tree ferns on Hawai`i Island (Becker 1976).

Tree fern density observed in the current study was almost identical to that measured at one site of an earlier study of East Rift vegetation near the Kahauale`a boundary, where 37.8 ferns/100$m^2$ were counted in a semi-isolated forest west of Pu`u `Ō`ō (Cuddihy *et al.* 1986). In the same study, carried out in 1983, sites at Nāpau Crater and Kāne Nui o Hamo had lower tree fern densities than those observed in the current study (24.4/100m^2 and 28.5/100m^2, respectively). This surprisingly large difference in tree fern density within East Rift forests over time may be evidence that tree fern numbers have been increasing in the upper part of the study area since the Pu`u `Ō`ō eruption began in 1983.

The higher density of tree ferns observed in the western half of the current study area may be related to either pig damage or volcanic activity. Forests of the western half of the study area are more accessible to public hunters and may have received more hunting pressure in the past. This western area is traversed by several trails; a greater level of human activity here may have served to reduce feral pig activity. When tree fern densities along the three long primary transects were compared, it appeared that the taller tree ferns (>1m) were largely responsible for the difference in the number of ferns observed in the eastern and western sections of the area. As tree ferns grow very slowly, it is unlikely that the difference in tree ferns observed in 1994 is due to the efforts of Park managers to reduce feral pig numbers above the barrier fence, a project that began in 1993 and continues at present. A recent study of tree ferns in forests near Thurston Lava Tube determined that the mean rate of growth in height of tree fern trunks was 5 cm/year (Walker and Aplet 1994). Assuming a similar rate of growth in East Rift forests, a 1-m tall tree fern would be approximately 20 years old. Past volcanic activity may also have played a role in the observed difference in the two areas; the easternmost transect (ca. 1 km east of the nearest transect) is the closest to Pu`u `Ō`ō, the source of tephra. Heavy cinder-fall has greatly altered forests near Pu`u `Ō`ō, and, although the easternmost transect 3A is 3 km away from the vent, it likely received a greater amount of tephra than did other transects. While tree ferns may have been temporarily affected by cinder-fall, tree ferns are known to be able survive and eventually recover, even in deep cinder areas (Becker 1976, Smathers and Mueller-Dombois 1974).

The decreased tree fern densities observed on the lower halves of the three main transects may be explained by the increasing dominance of uluhe at lower elevations in the study area. In a study of tree ferns in different vegetation types on Hawai`i Island, Becker (1976) found vastly lower densities of tree ferns in uluhe-dominated forests, when compared with more closed `ōhi`a or `ōhi`a/koa forests at the same elevation with similar substrate type and soil depth. The observed decrease in soil depths in the lower halves of two of the primary transects is additional evidence that the transects crossed a transition area between vegetation types, at least in the eastern part of the study area. It is possible that the observed lower numbers of young tree ferns on the lower halves of transects may have been influenced by pig predation and trampling, as young tree ferns have been shown to be vulnerable to pigs in other studies (Diong 1983). However, if pig feeding were the explanation for lower tree fern densities in this lower-elevation area, we would also expect to see lower densities of mature tree ferns, as the larger ferns (>1 m tall) provide more food per fern than do smaller plants. As there was no difference in density of large tree ferns in the upper and lower sections of the main transects, pig predation seems a less likely interpretation than does forest type to explain the variation noted in small tree fern density.

The area covered by uluhe appears to have greatly explanded over the last two decades in the Park's East Rift forests (Jacobi unpublished, Loh and Tunison in prep.); the presence of large tree ferns in vegetation now dominated by uluhe may be an indication of type conversion of former closed `ōhi`a forest. Environmental changes wrought by the ongoing eruption (i.e. canopy opening, deep tephra deposits) may have set back normal primary succession of closed `ōhi`a forest from uluhe-dominated stands, a process that usually takes place within 150 years of substrate formation and original plant invasion (Mueller-Dombois and Loope 1990).

<u>Density of `Ōlapa</u>

`Ōlapa trees are known to be vulnerable to damage from ungulates; feral and domestic cattle, in particular, may do great damage to the species by stripping bark and girdling small to medium-size trees. This species was chosen for intensive monitoring because of the potential for damage by feral pigs and also because of the importance of `ōlapa as a co-dominant canopy species and a host for endemic *Drosophila* flies. Overall, `ōlapa appears to be successfully maintaining a stable population in East Rift forests, despite the presence of feral pigs. The results from this study indicate that adequate reproduction is occurring to maintain the `ōlapa population throughout the study area. However, the low numbers of saplings imply that replacement is slow, and the relatively low numbers of terrestrial saplings imply that feral pigs may be subtly affecting `olapa regeneration. No such concern is warranted for larger trees, which are clearly capable of coexisting with feral pigs, as evidenced by the high average number of terrestrial plants in diameter classes of 1-20 cm. A similar reverse J-shaped population distribution of `ōlapa was observed more than a decade ago at two East Rift sites in or near the current study area (Cuddihy *et al.* 1986); this corroboration indicates that the `ōlapa population stability noted in the current study is not a new phenomenon on the East Rift.

These findings do not mean that feral pigs are not influencing `ōlapa reproduction in certain portions of the East Rift forests. The differences in density of seedlings and saplings detected in the western versus the eastern, unprotected part of the study area imply that feral pigs are reducing the number of young, terrrestrial `ōlapa in the eastern part of the study area. However, larger, well-established `ōlapa trees are more abundant to the east, perhaps because of increased light resulting from canopy openess associated with past volcanic cinder-fall. It appears that whatever potential impact feral pigs may have on light-loving `ōlapa is compensated for by the present enviromental conditions in the eastern part of the study area. Another factor likely influencing the establishment of young `ōlapa is the type of seedbed available for germination and growth of seedlings; a recent study in Hakalau Forest National Wildlife Refuge demonstrated that `ōlapa prefers decaying wood and root mats as seedbeds and that mineral soil is not a good site for seed germination (Scowcroft 1992).

The trend of decreased sapling density in the lower portions of the three main transects, where pig activity is presumed to be greater because of proximity to the open end of the barrier fence, also indicates that feral pigs are negatively impacting some size classes of `ōlapa. While the easternmost transect 3A consistently had a greater density of `ōlapa saplings and trees than did the other two main transects to the west, these `ōlapa were concentrated in the upper portion of the transect, where light was maximized by a thin upper forest canopy and pig-deterring tephra deposits were deepest.

Vegetation in Pig-Disturbed Plots

Recently pig-disturbed sites were selected for vegetation monitoring in 1994, to facilitate evaluation of short-term change with reduction of feral pigs and to allow for later documentation of long-term recovery of vegetation, should the barrier fence technique of pig control be successful. Almost all of the Park's East Rift forests exhibit signs of long-term, persistent damage from feral pig activities; the only exceptions are inaccessible pit craters protected from pigs by steep crater walls. Ground cover and woody plant density data from all 39 plots characterize the study area forests as depauperate in native woody species with a very sparse ground cover dominated by ferns. Tree ferns were particularly hard-hit in disturbed plots, where 10% of the ferns (on average) showed signs of pig predation, and 80% of disturbed plots contained such damaged or killed tree ferns. This damage and subsequent death of tree ferns, indisputably due to pigs, was likely the reason for the far lower density of tree ferns observed in disturbed plots than was found in plots throughout the East Rift study area. Relatively large tree ferns >1-2 m tall were the primary target of the feeding activities of feral pigs.

The results of remonitoring 20 Park plots after 1.5-2 years give some indication of the direction of short-term vegetation change. The observed decrease in exposed soil was likely related to the lessened digging and rooting activity of pigs, resulting from Park feral pig control efforts. Likewise, the decline in cover of pig-damaged tree ferns was an indication of lessened damage to these palatable plants coupled with the disintegration of trunks previously killed by pigs. The most dramatic change over 1.5-2 years was the great increase in the cover of two alien species: Hilo grass and scaly swordfern. These two plant species will likely become dominant components of the ground cover of pig-disturbed forests, at least temporarily.

The expansion of Hilo grass is particularly disturbing because of its demonstrated ability to persist for decades and prevent the reproduction and re-establishment of native woody plants (Loope 1992, Anderson *et al.* 1992). This grass is known to form dense mats even in forests with poor soil (Smith 1985), and it has long been recognized as a serious threat to Hawai`i's native forests (Giffard 1918, Merrill 1941). Although Hilo grass has been in Hawai`i since 1840, the species continues to intensify and expand its range (Cuddihy and Stone 1990). Less is known about the potential negative impacts of scaly swordfern. The species is a relative newcomer to Hawai`i (Wagner 1950), and its spread and replacement of native plants have been largely unheralded, perhaps because of its morpological resemblance to the common native fern kupukupu (*Nephrolepis exaltata*). The large increase in cover of this fern in vegetation plots, as well as its rise in frequency along transects between surveys mark this species as one to monitor for future expansion.

The short-term increase in alien species cover should not be assumed to be indicative of the eventual composition of previously disturbed forests. Other studies have also noted increased cover of invasive alien species within the first few years of protection from feral pigs (Stone *et al.* 1992). Longer-term monitoring of disturbed forests has provided more promising results demonstrating the ability of native plants to persist and recover (Katahira 1980, Pratt and Abbott in prep., Loope and Scowcroft 1985). The eventual species composition of East Rift forests can scarcely be guessed, but it is probable that feral pig removal and long-term management of the worst alien plant threats will result in a forest with greater native plant diversity and abundance than what currently exists. Forests never damaged by feral pigs, such as those of pit craters (Belfield 1998) and pig-free kipuka (Higashino and Stone 1982), allow us to visualize the appearance of an undisturbed forest and represent a potential management goal. Such undisturbed natural forests demonstrate that native plant species diversity, density, and cover should be far greater in rain forests of the East Rift. "The potential resilience of endemic biota" should not be underestimated (Mueller-Dombois and Loope 1990).

The small increases in native woody plant densities noted in the interval between vegetation plot monitoring periods reiterate the recovery potential of native plants in these forests. Important understory species, such as `ōlapa, *Cyrtandra* spp., alani, and even *Clermontia*, displayed higher densities of young plants after only a short period of protection from feral pigs. Tree ferns, which are perhaps the most important species of the understory in terms of shade production, system stability, and lessened invasibility (Mueller-Dombois *et al.*1981), also exhibited an impressive increase in density within remonitored vegetation plots. In the absence of high levels of pig activity, tree ferns were able to re-colonize disturbed plots and grow into the <0.5 m height category during the 1.5-2 years of the study. The only Park plots that did not display higher tree fern densities over the monitoring period were near a water hole, in an area likely to have residual pig activity.

Feral Pig Activity

Feral pig density, as estimated from frequency of pig activity, was relatively low in the forested East Rift study area, even before systematic control efforts began. In June 1993, prior to the initiation of control work by Park personnel, the mean frequency of pig activity was only 1.3%, resulting in a pig density estimate of 1.9/km^2. This pig density is relatively low, compared with other regions of the Park where pig removal was eventually achieved. For example, in `Ōla`a, a montane rain forest, feral pig density was estimated as 5.3/km^2 just before eradication of animals from the control unit (Anderson and Stone 1994). Pig density estimates at other control units within the Park have ranged from 0.8 to 6.53/km^2, with the lower estimates coming from drier, high-elevation sites (Anderson and Stone 1994, Katahira *et al.* 1993). Elsewhere in the State, pig densities prior to control efforts have been much higher, such as in the rain forests of Kīpahulu Valley, Maui, where densities of 6-14 animals/km^2 were reconstructed from removal and pig age data (Anderson and Stone 1993). The density of pigs in East Rift forests may be low because of past eruptive activity and cinder-fall, which may drive pigs downslope away from the noise of lava fountaining and the accumulation of sharp tephra at ground level.

Data from quarterly pig activity monitoring demonstrated an increase in pig activity and density along Park transects until the end of 1993, when the mean density on all Park transects was estimated at 5.7 pigs/km^2 . In 1994 and 1995 there was a consistent decline in pig activity resulting in an estimated density of 2.3 pig/km^2 by the end of the study in January 1996. Although pig activity transects are deemed ineffective for detecting pig population density when pig densities fall below 1 pig/km^2, such monitoring is thought to provide a good measure of control effectiveness above this limit (Anderson and Stone 1993). During the same time period that pig populations were declining in the Park above the barrier fence, pig activity remained high and pig population estimates were many times greater in Kahauale`a forests, an uncontrolled and largely unhunted area adjacent to the Park north of the study site. These findings suggest that the Park's pig snaring efforts (preceded by a brief period of staff hunting) reduced the feral pig population in the area upslope of the barrier fence within two years of the initiation of snaring. However, there is some margin of error in using pig activity along transects to estimate pig densities. At low pig densities, activity along transects may well underestimate the actual number of pigs in an area (Anderson and Stone 1993). In the current study, the March 1994 monitoring resulted in an estimate of 2.1 pigs/km^2 for transect 2 , while the March tally of pigs caught in the snares on and near this transect was 13 in an area roughly 3 km^2 (H. Hoshide, pers. comm. 1997).

Success in lowering pig density was not the same throughout the study area. A decline in pig activity and density was not observed on the easternmost transect 3A, which is beyond the open end of the barrier fence. In fact, the final monitoring period data indicated that pig density here (tr 3A) was similar to that of Kahauale`a, where no systematic pig control was taking place. Transect 3, which ends near the open terminus of the barrier fence, also showed no decrease in pig activity or density for the first two years of the study. These data reveal that no significant reduction in the feral pig population was taking place at and near the open end of the barrier fence. Evidence of continued pig activity and estimates of higher pig densities along eastern transects near the end of the barrier fence are supported by catch data collected during snaring by Resources Management personnel (Hoshide unpublished). Throughtout 1993 and the early part of 1994, most of the pigs caught in snares were captured in snare groups near the end of the barrier fence and at a few points near the fence to the west. This geography of successful snaring implies that pigs were continuing to ingress at the fence terminus and were using the fence line as a route to the western portion of the study area. Even at the end of 1995, pig catches continued to be concentrated near the eastern end of the fence, although by this time newer snare sets in the upper part of transect 2 and near a permanent waterhole not far from the base of the 1840 flow were also successfully trapping pigs. The further implication here is that a relatively large population of pigs remains just outside the control area, and, as long as the fence remain open, this uncontrolled area will continue to act as a reservoir for animals that may enter the forests above the fence and add to the resident pig population.

While the barrier fence and snaring approach to feral pig control seemed to reduce numbers of pigs present in the western and northern parts of the study area farthest from the open end of the fence, vegetation recovery was not particularly noticeable in these areas. The frequency of `ōhā or *Clermontia* growing terrestrially (and therefore accessible to pigs) decreased during two years of the study, implying continued predation by pigs. There was some indication from remonitored pig-disturbed plots that tree ferns were beginning to increase in smaller size classes, perhaps heralding the beginning of recovery for this most favored of pig foods (Cooray and Mueller-Dombois 1981, Diong 1983). The expansion in cover of several alien grass and fern species and the decline in exposed soil in disturbed plots indicate that pig digging and other disturbance had subsided, at least in the areas with the worst disturbance in 1994.

Only long-term monitoring will reveal the direction and predictive value of presumed indicators of change and recovery. Other studies of the impacts of feral pigs and vegetation recovery after pig removal have highlighted *Clermontia* spp., tree ferns (*Cibotium* and *Sadleria*), other terrestrial ferns, sedges, koa (*Acacia koa*), the native lily pa`iniu (*Astelia menziesiana*), and `ie`ie as indicator species for assessment of the activity of feral pigs in rain forests (Cooray and Mueller-Dombois 1981, Diong 1983, Stone and Loope 1987, Anderson and Stone 1994, Pratt and Abbott in prep.). Future monitoring should focus on such indicator species to determine short-term change with pig control (or eventual removal), and data on the composition and structure of vegetation should be systematically collected for evaluation of long-term recovery.

MANAGEMENT CONSIDERATIONS

1) Consideration should be given to closing the barrier fence and making the control unit an exclosure. (Note: This enclosure was accomplished in 1999.) If Park managers wish to eradicate feral pigs from the study area to protect the natural resources of the East Rift forests and reduce the effort and time required to remove pigs, as is typically the Park's goal (Hone and Stone 1989), it will be necessary to close the barrier fence and provide a true exclosure when eruption conditions permit. Stone (1995) has argued that exclusionary fencing and rapid pig eradication is the most humane and

ethical treatment of animals in protected areas, because fewer animals die overall and suffering is minimized.

2) Monitoring of alien plants and vegetation recovery should be continued at an interval of <10 years. While Park researchers have gathered data on montane rain forests, mesic forests, and dry koa parkland, little is known about the potential for recovery of low to middle-elevation rain forests in areas with serious alien plant problems and the natural perturbations of volcanic fuming and cinder outfall. Because of the short-term nature of the current study (2.5 years), data presented here can only be considered a baseline study of the status of alien plants, rare plants, indicator species, and vegetation structure in East Rift forests. Fortunately, some comparative data were available from previous surveys and research projects. Remonitoring of disturbed plots and collection of transect data in 5-10 years will likely reveal much information critical to the efficient management of the Park's East Rift rain forests. Remonitoring will also serve to evaluate the success or failure of feral pig control and any other management activities undertaken in this Special Ecological Area.

3) Alien plants should be controlled, at least in the most intact and species-rich areas. Priority species for control are yellow Himalayan raspberry, cane tibouchina, firetree, and strawberry guava. Several of the most intact, diverse, and promising areas requiring some level of alien plant control are Kāne Nui o Hamo, the tall and dense forest near Nāpau Crater, and the transition forest in the southwestern part of the SEA near the N āulu trail.

4) Several missing and depleted rare and endangered plant species should be considered for propagation and outplanting to the East Rift forests in or near their former range. Suggestions for reintroduction or augmentation are the endangered pendent kihi fern and four "species of concern": `ānini, jewel orchid, `awapuhi a Kanaloa, and the endemic mint *Phyllostegia floribunda*. Rare plants that are currently severely restricted in East Rift forests or are missing from the region should also be considered for augmentation or restoration to the SEA; these include pala fern, kilioe, and *Phyllostegia vestita*. In all cases, propagation material would have to come from adjacent lands out of the Park or from Park populations at some distance from their former range in East Rift forests.

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FIGURES

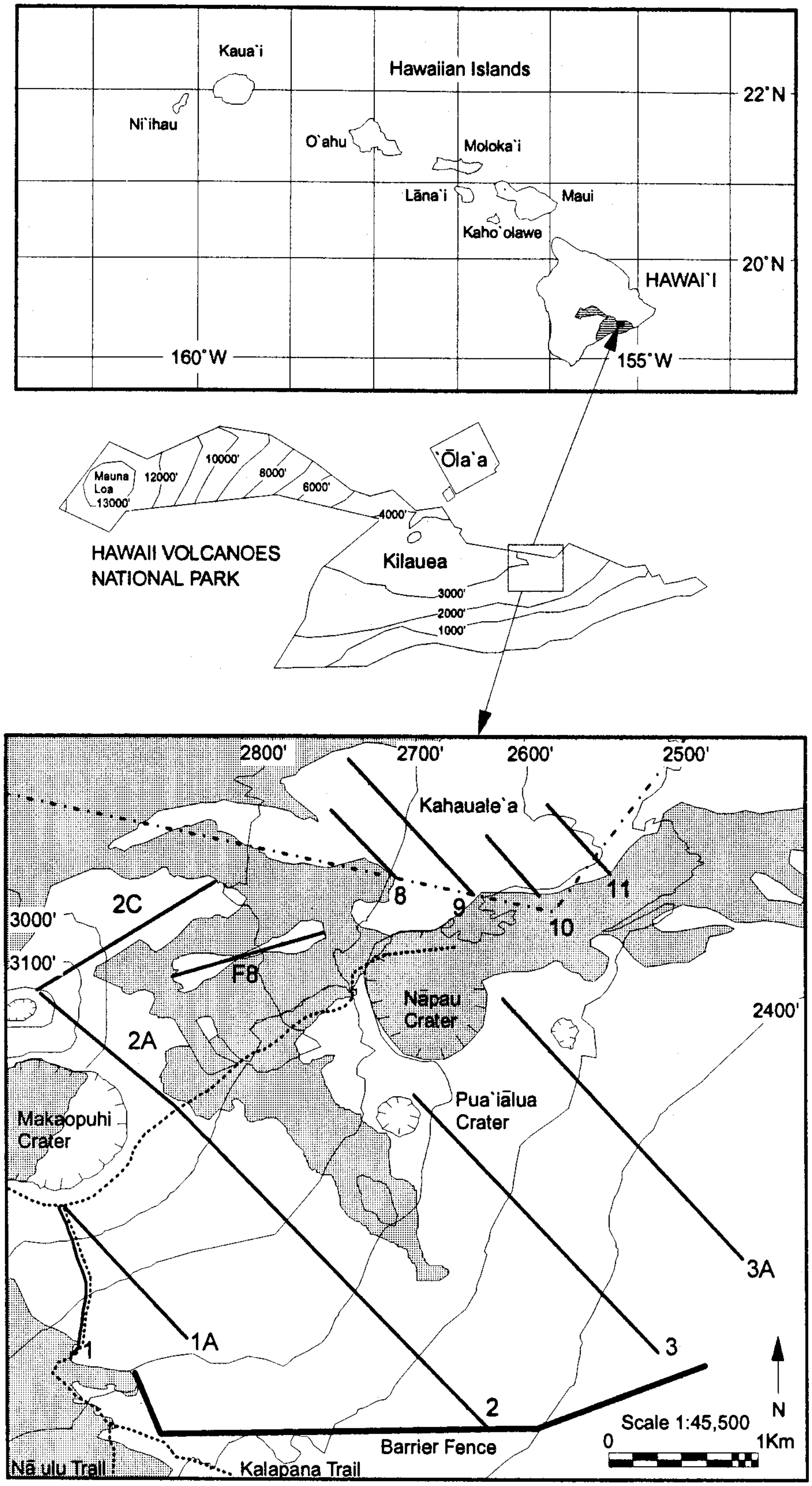


Figure 1. The East Rift study area in Hawaii Volcanoes National Park, island of Hawai`i, showing the barrier fence, primary trails, transects, and historic lava flows.

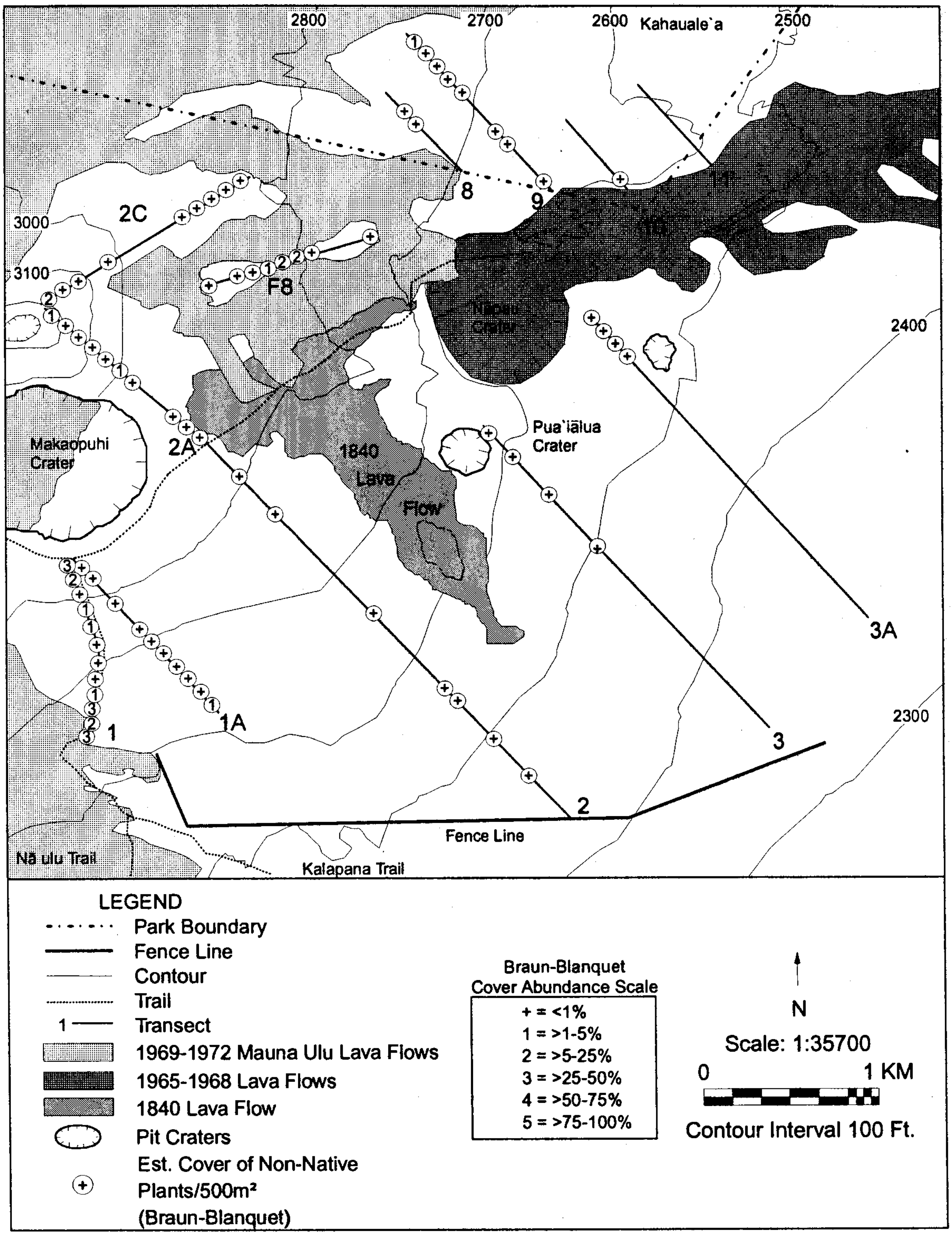


Figure 2. Distribution and estimated abundance of broomsedge (*Andropogon virginicus*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

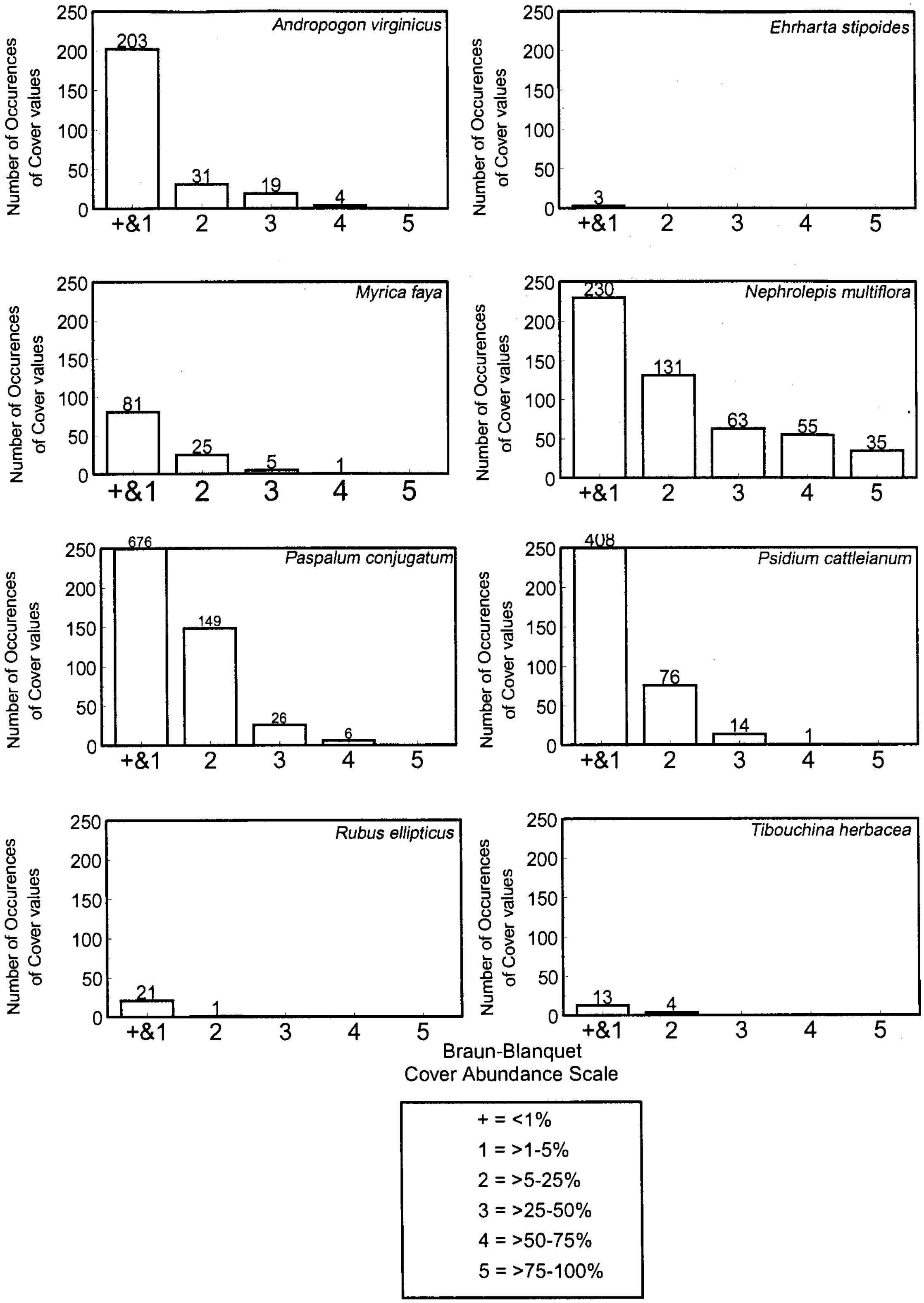


Figure 3. Frequency of occurrence of eight alien plant species in five categories of cover-abundance along transects in East Rift forests, Hawaii Volcanoes National Park.

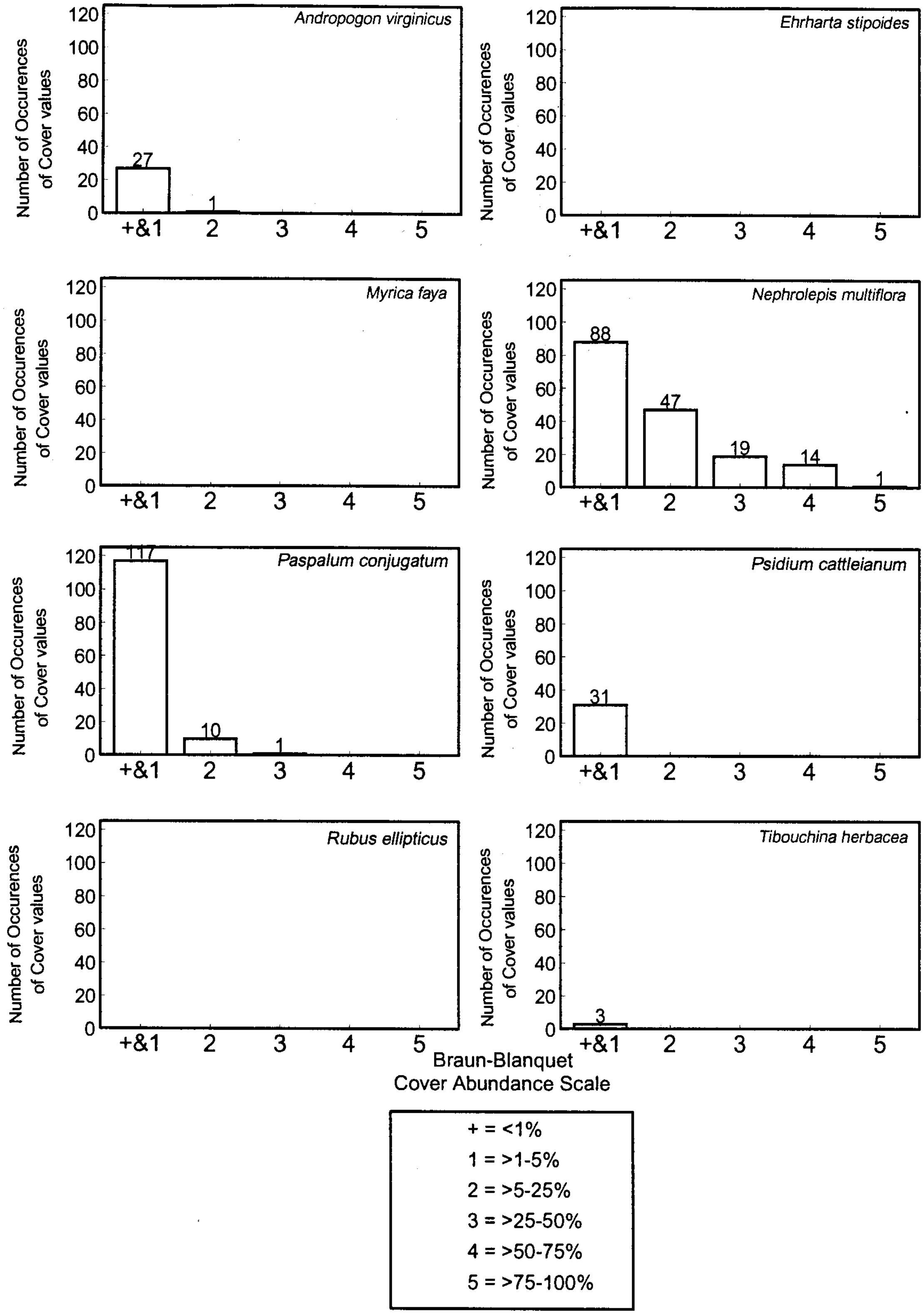


Figure 4. Frequency of occurrence of eight alien plant species in five categories of cover-abundance along four transects in forests of Kahauale'a.

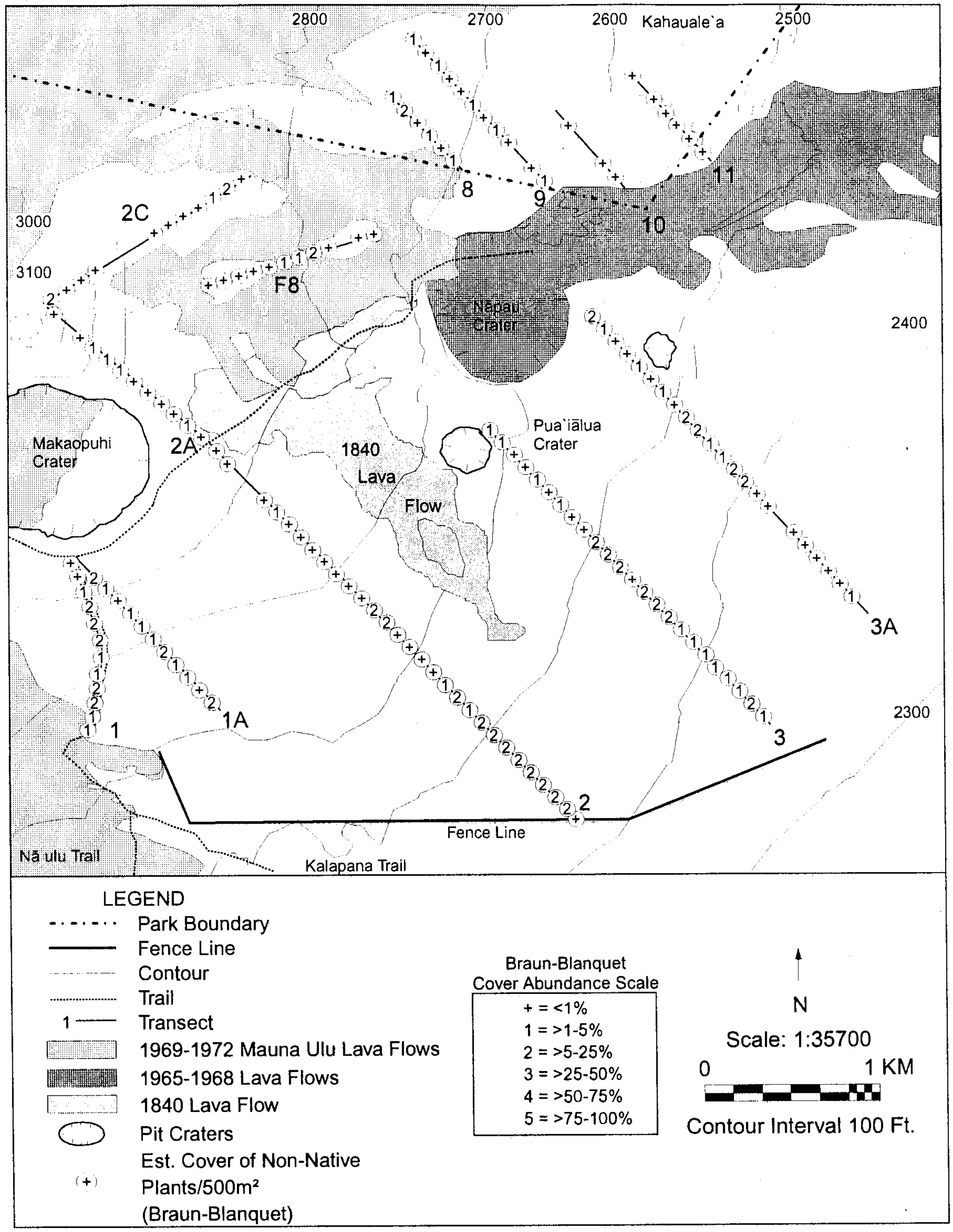


Figure 5. Distribution and estimated abundance of Hilo grass (*Paspalum conjugatum*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

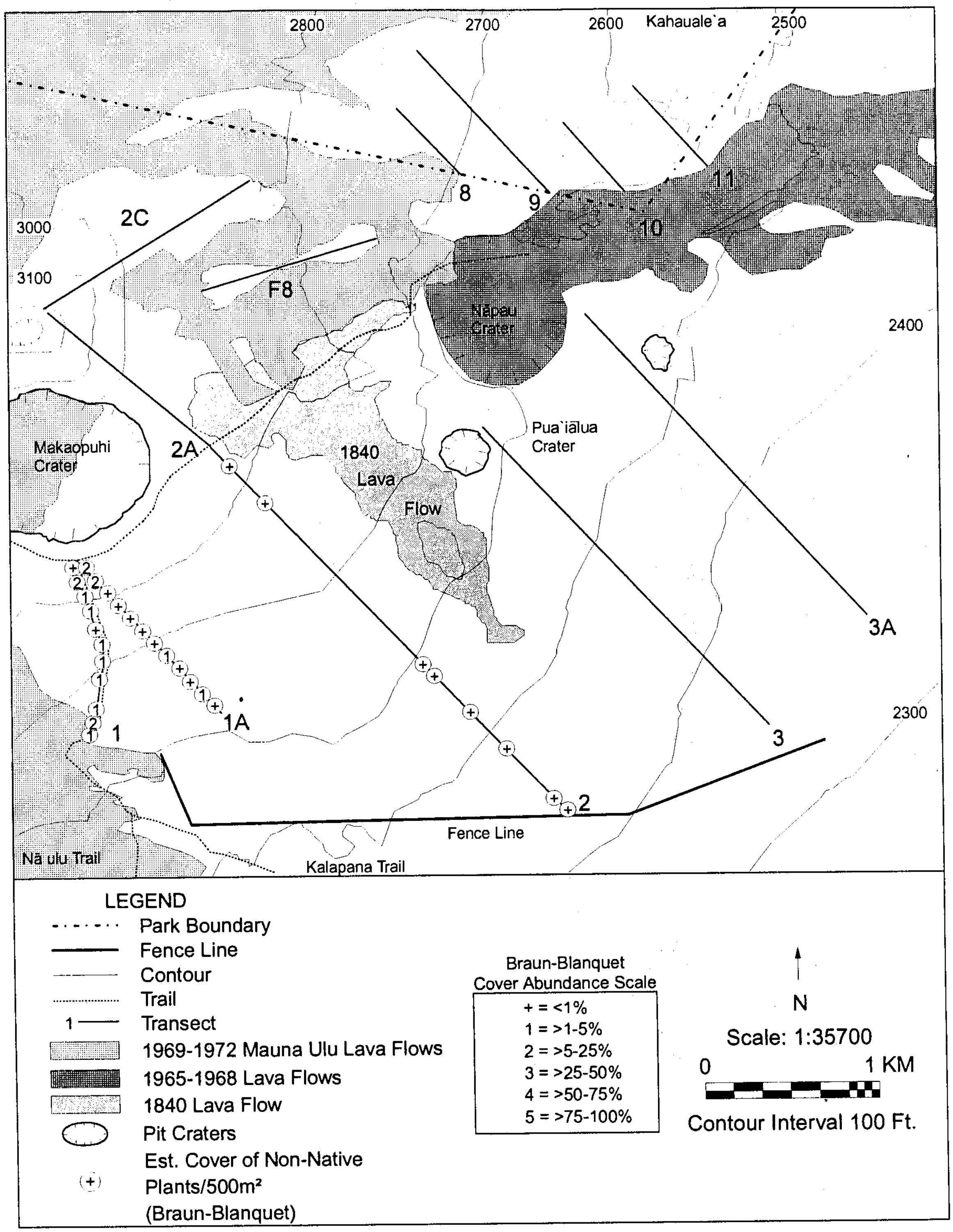


Figure 6. Distribution and estimated abundance of firetree (*Myrica faya*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

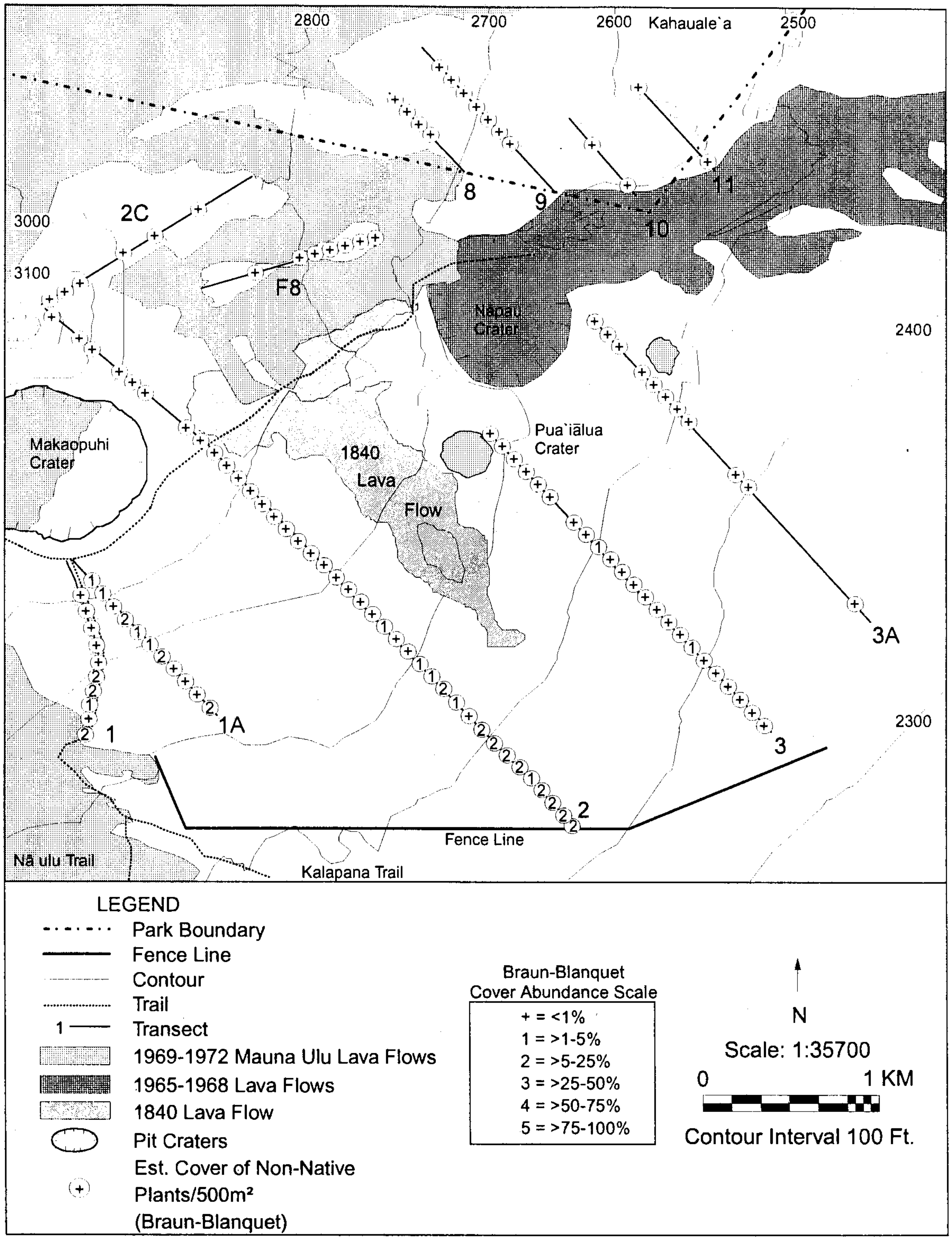


Figure 7. Distribution and estimated abundance of strawberry guava (*Psidium cattleianum*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

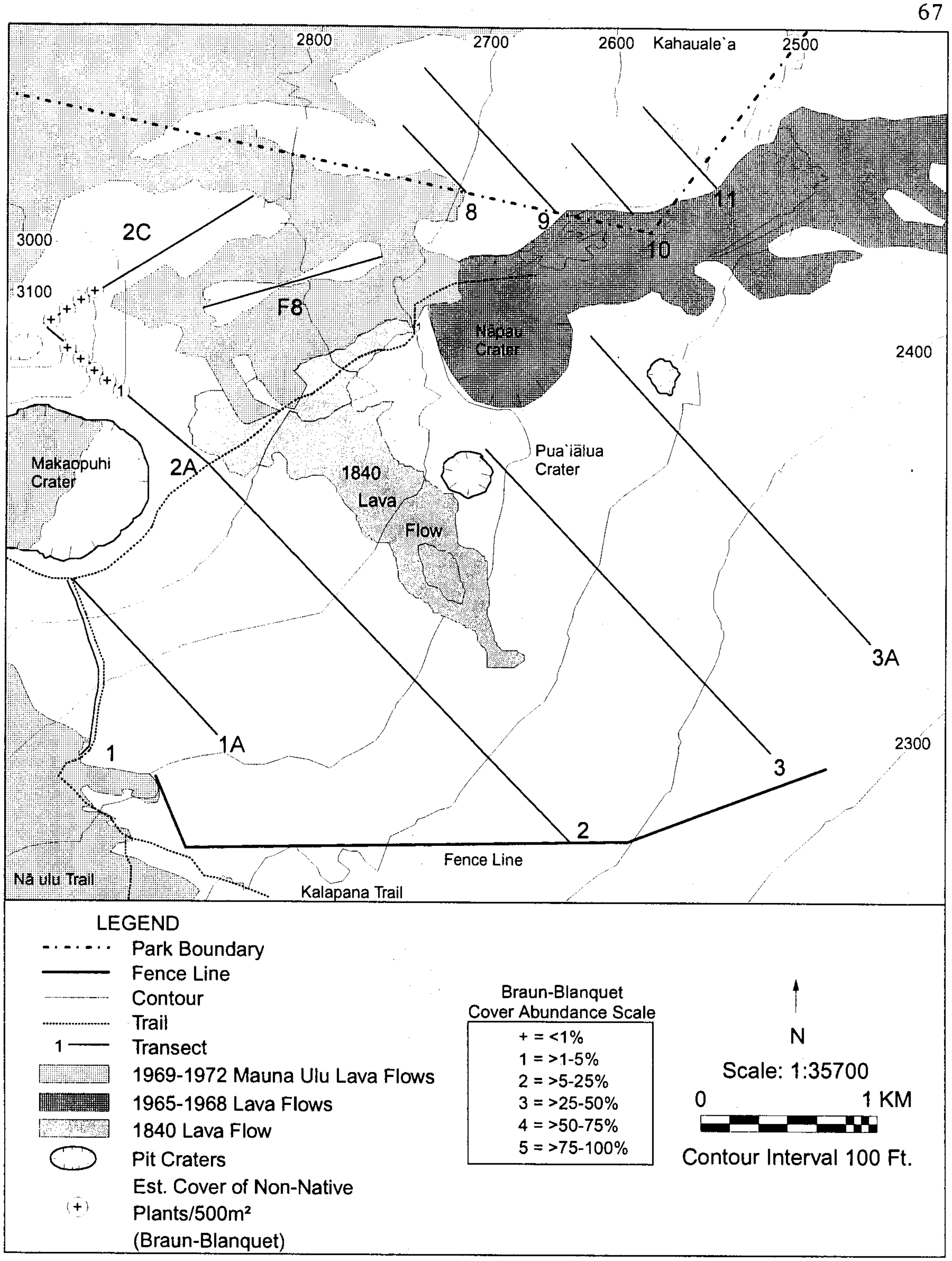


Figure 8. Distribution and estimated abundance of yellow Himalayan raspberry (*Rubus ellipticus*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

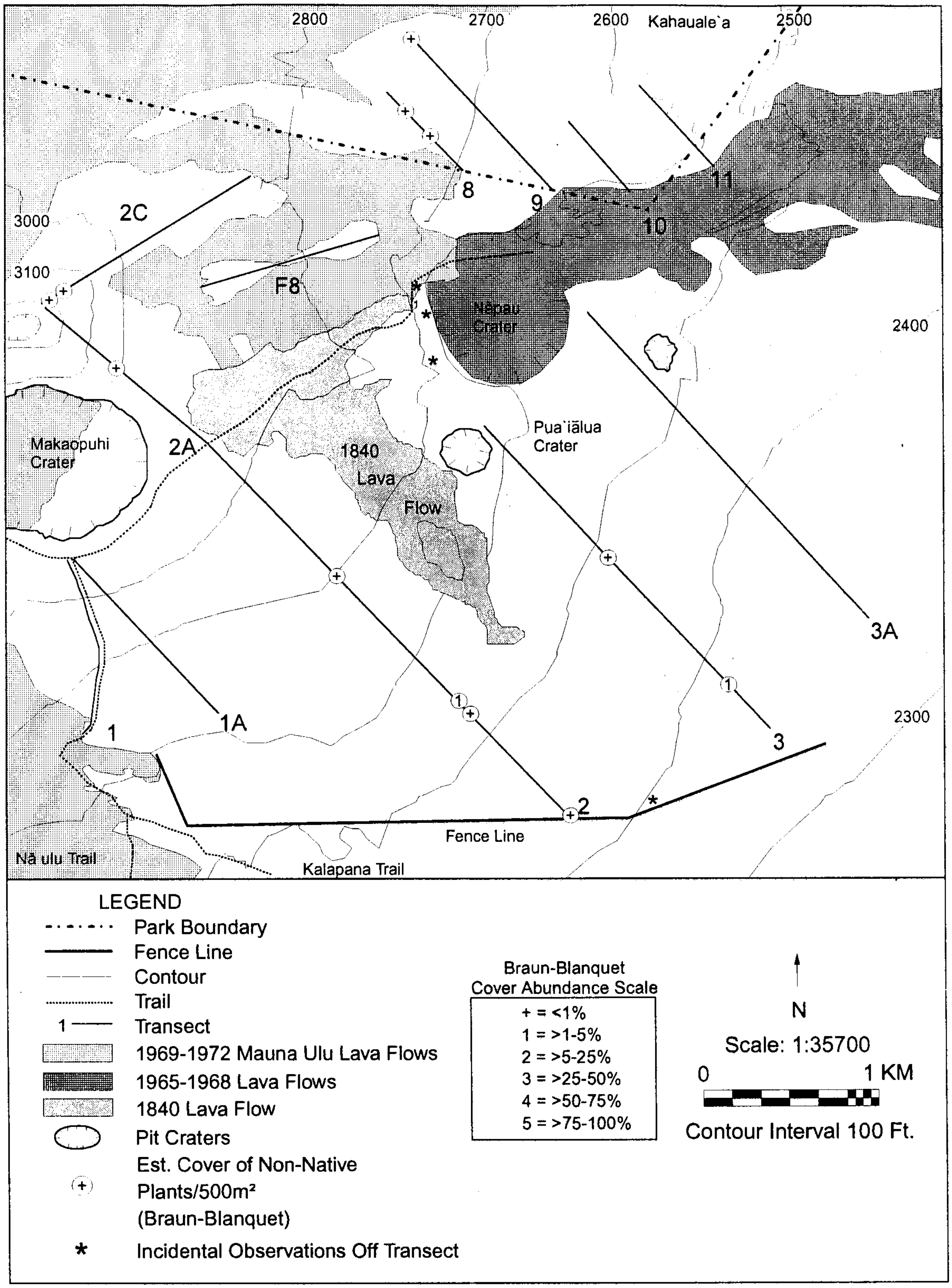


Figure 9. Distribution and estimated abundance of cane tibouchina (*Tibouchina herbacea*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

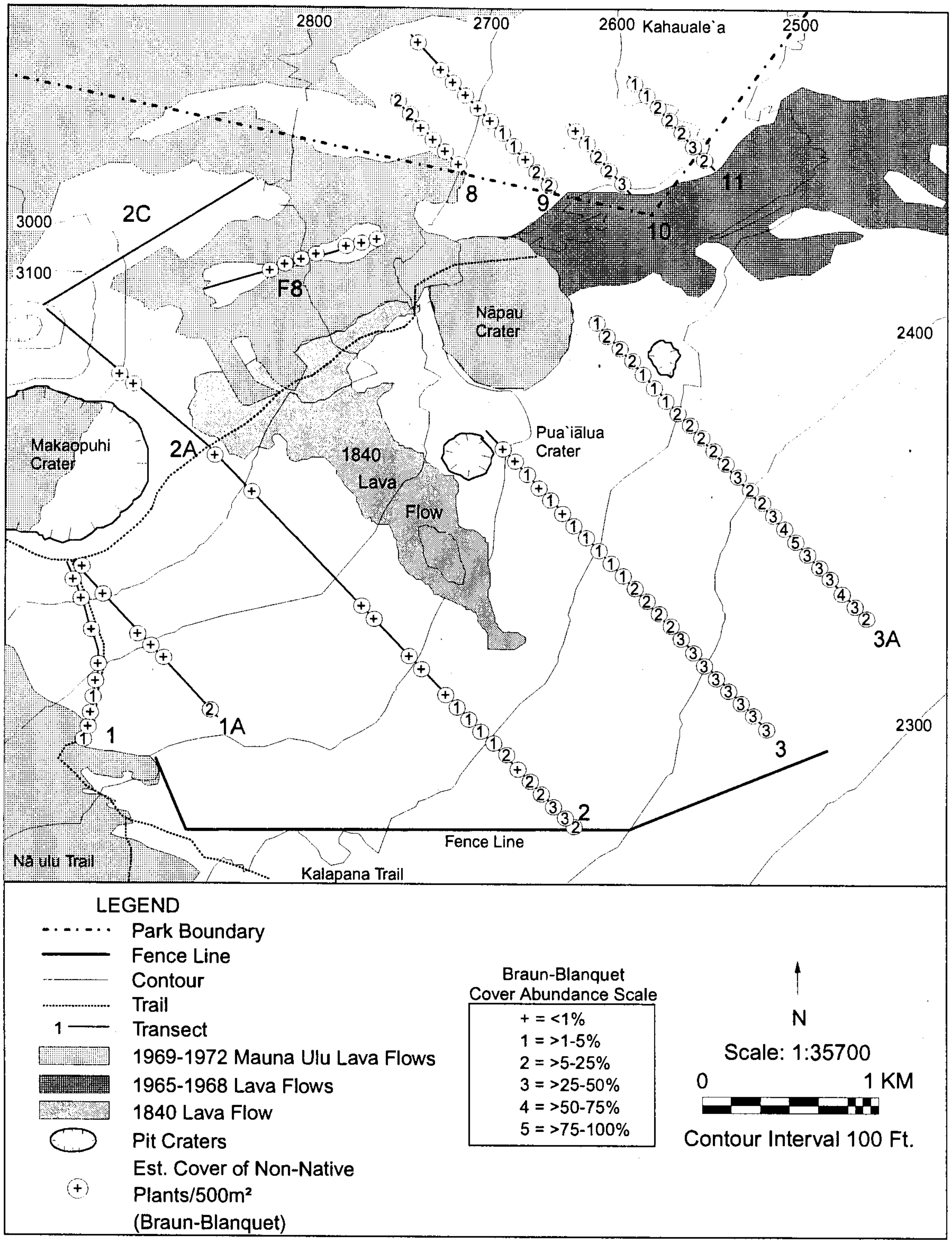


Figure 10. Distribution and estimated abundance of scaly swordfern (*Nephrolepis multiflora*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

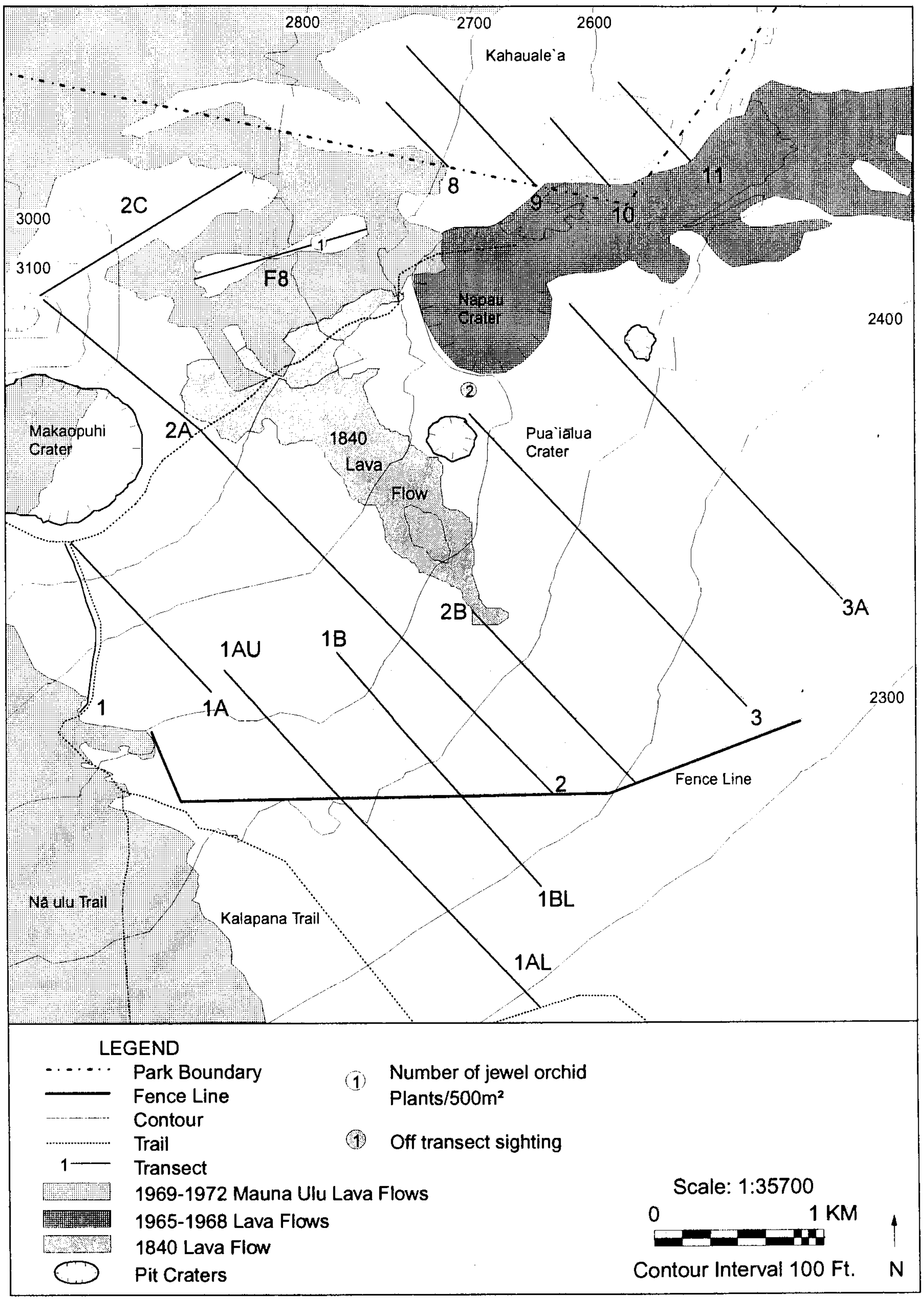


Figure 11. Distribution of jewel orchid (*Anoectochilus sandvicensis*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

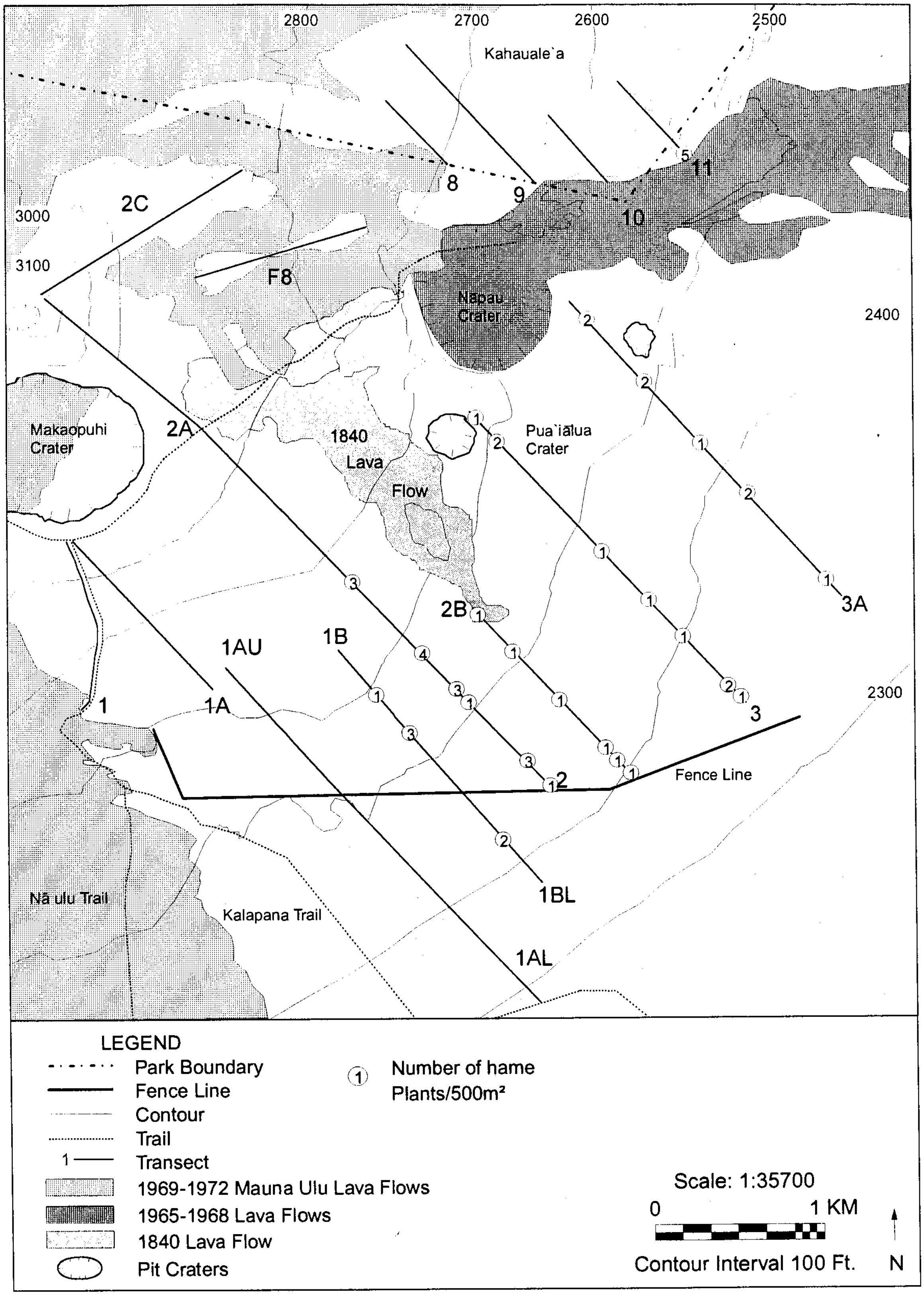


Figure 12. Distribution of hame (*Antidesma platyphyllum*) in East Rift forests near a feral pig barrier fence, Hawaii Volcanoes National Park.

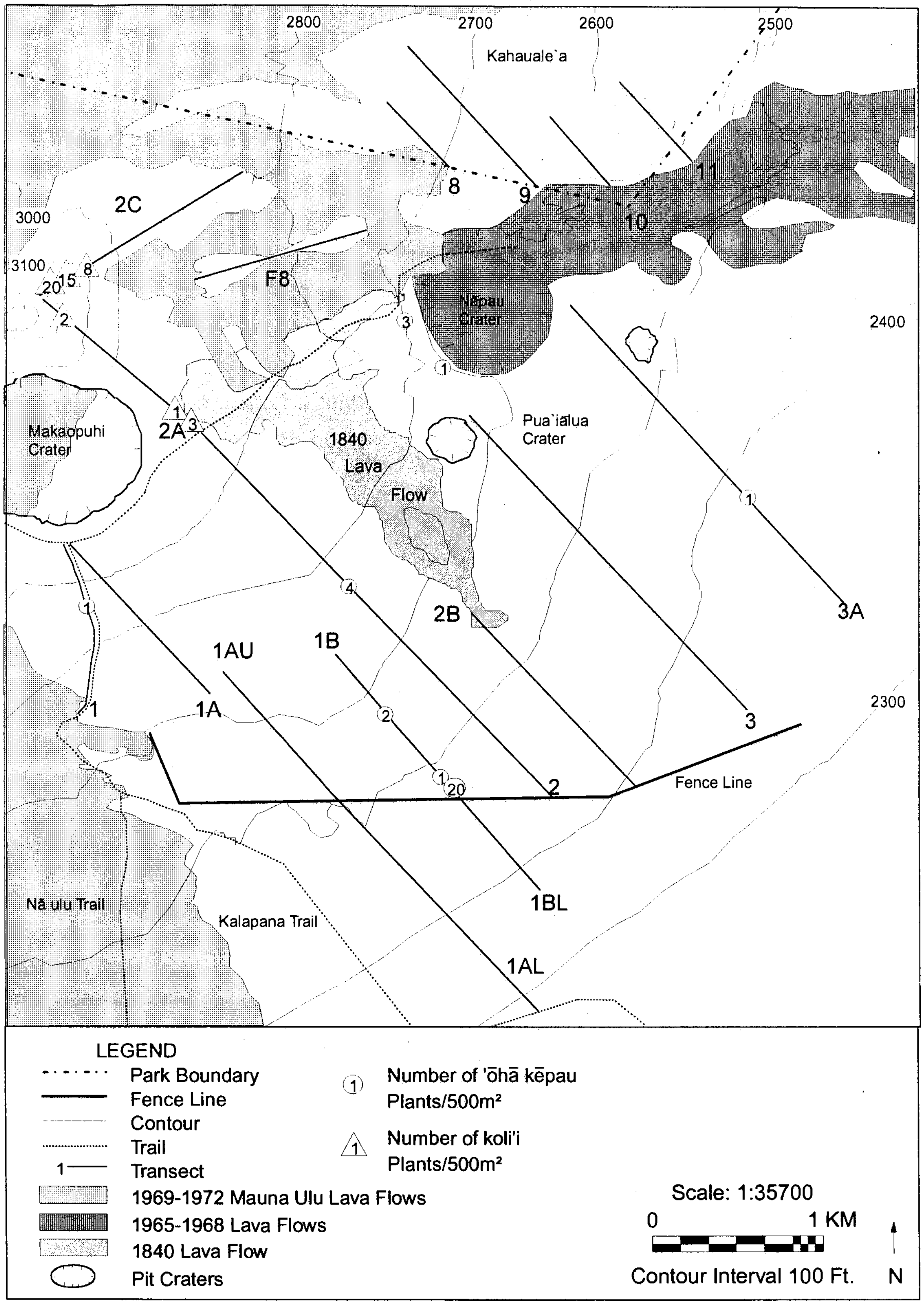


Figure 13. Distribution of 'ōhā kēpau (*Clermontia hawaiiensis*) and koli'i (*Trematolobelia grandifolia*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

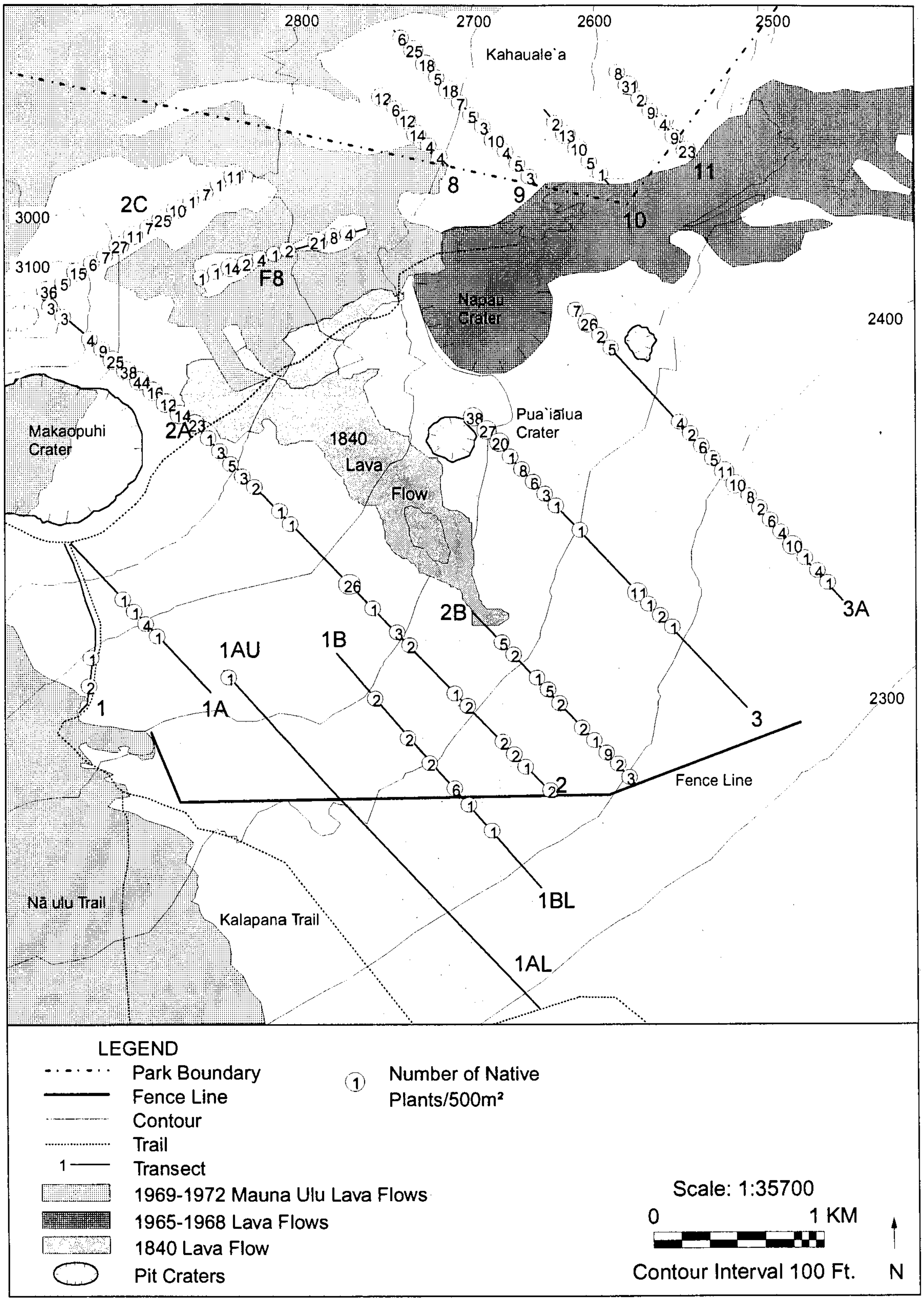


Figure 14. Distribution of ʻōhā (*Clermontia parviflora*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

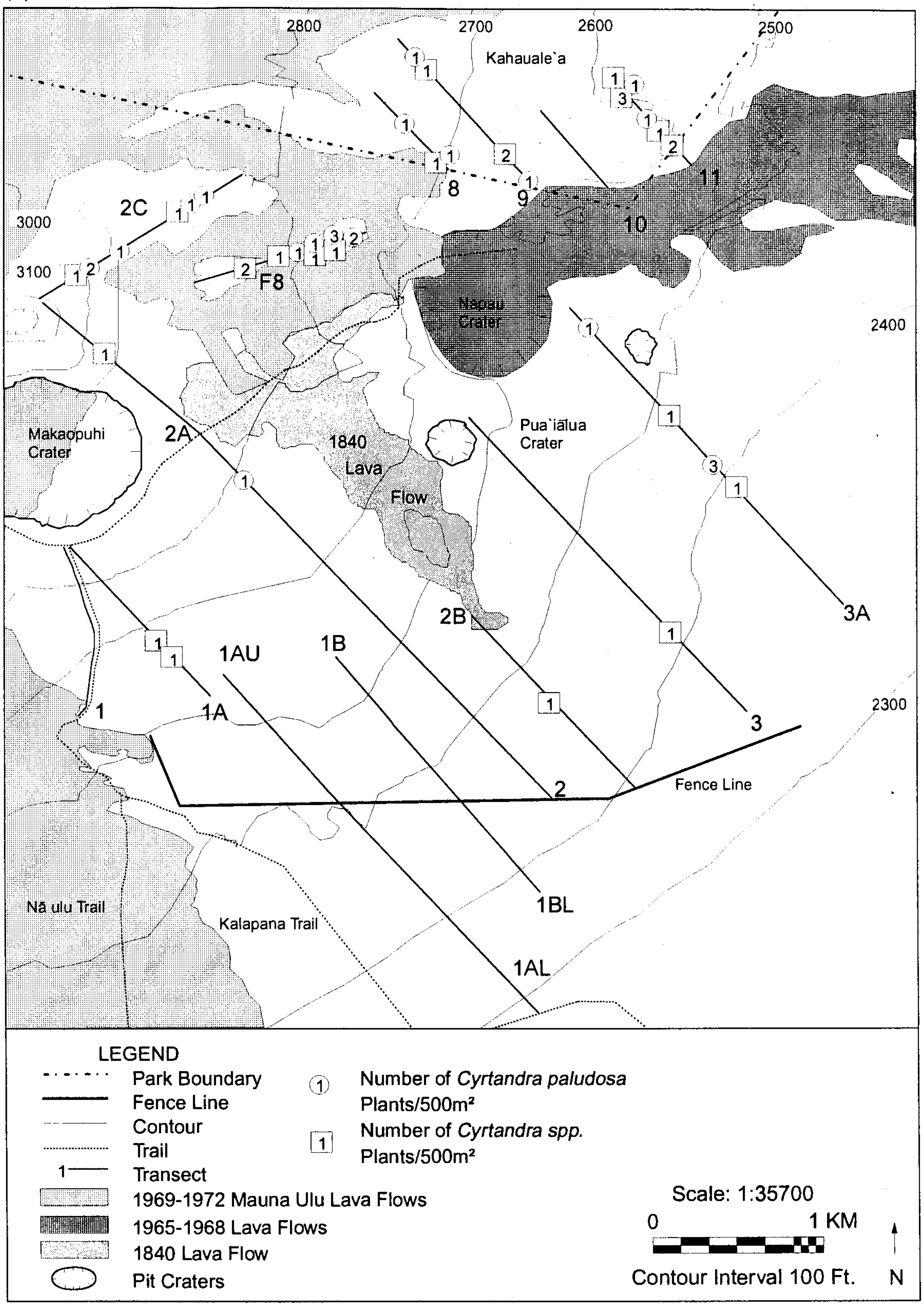


Figure 15. Distribution of hahala (*Cyrtandra paludosa*) and *Cyrtandra spp.* in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

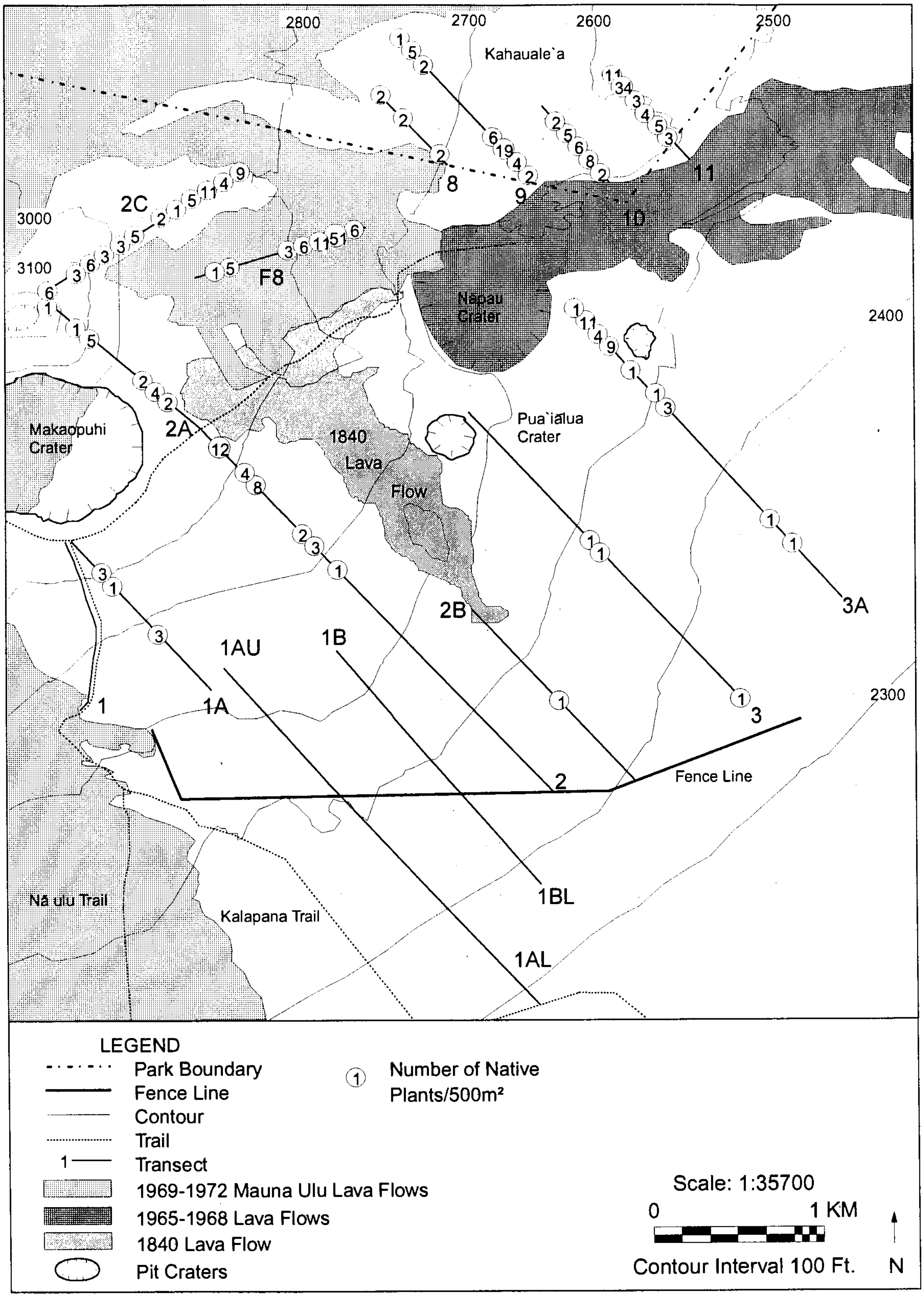


Figure 16. Distribution of 'ilihia (*Cyrtandra platyphylla*) in East Rift forests above a feral pig barrier, Hawaii Volcanoes National Park.

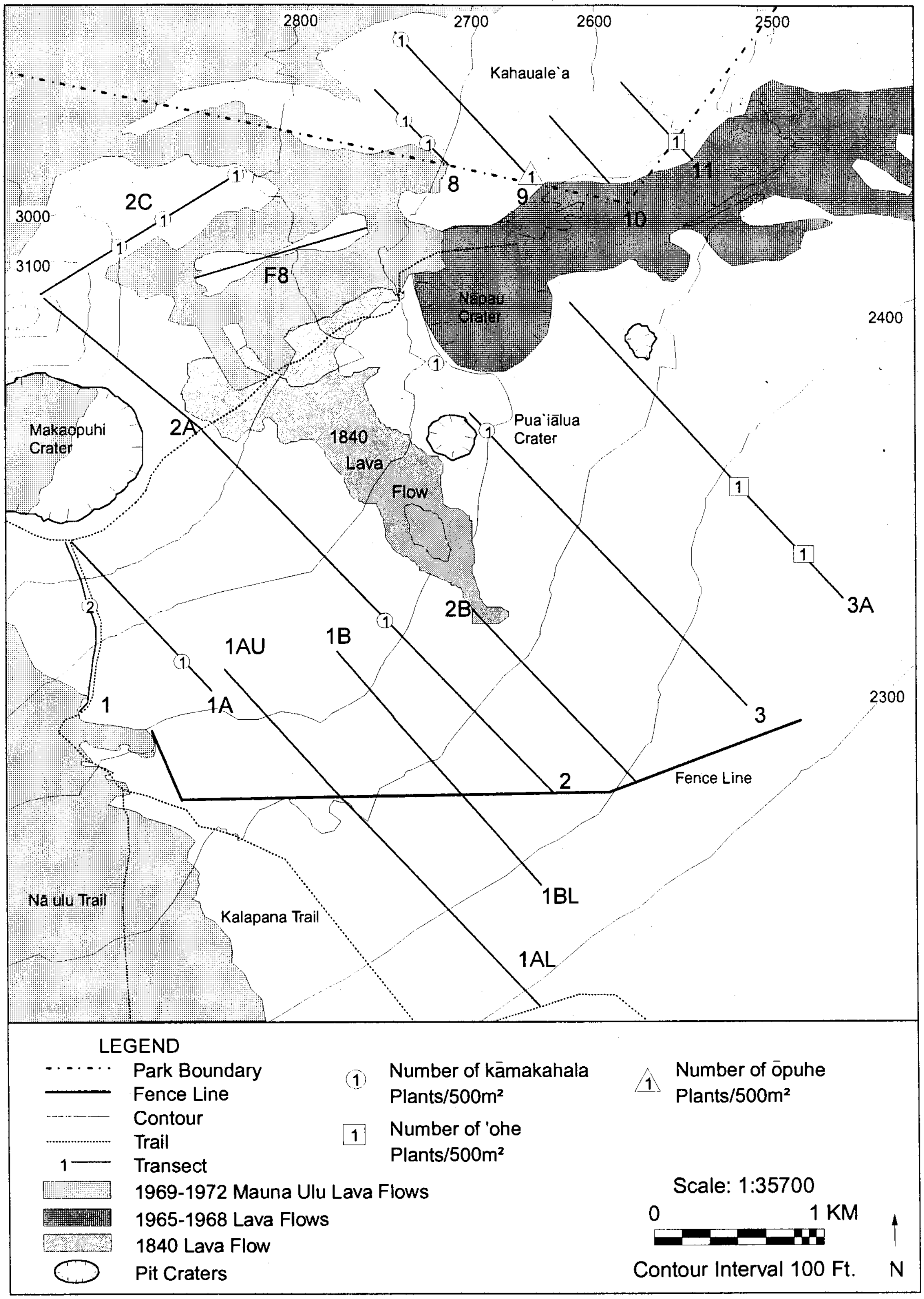


Figure 17. Distribution of kāmakahala (*Labordia hedyosmifolia*), ōpuhe (*Urera glabra*), and 'ohe (*Tetraplasandra hawaiensis*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

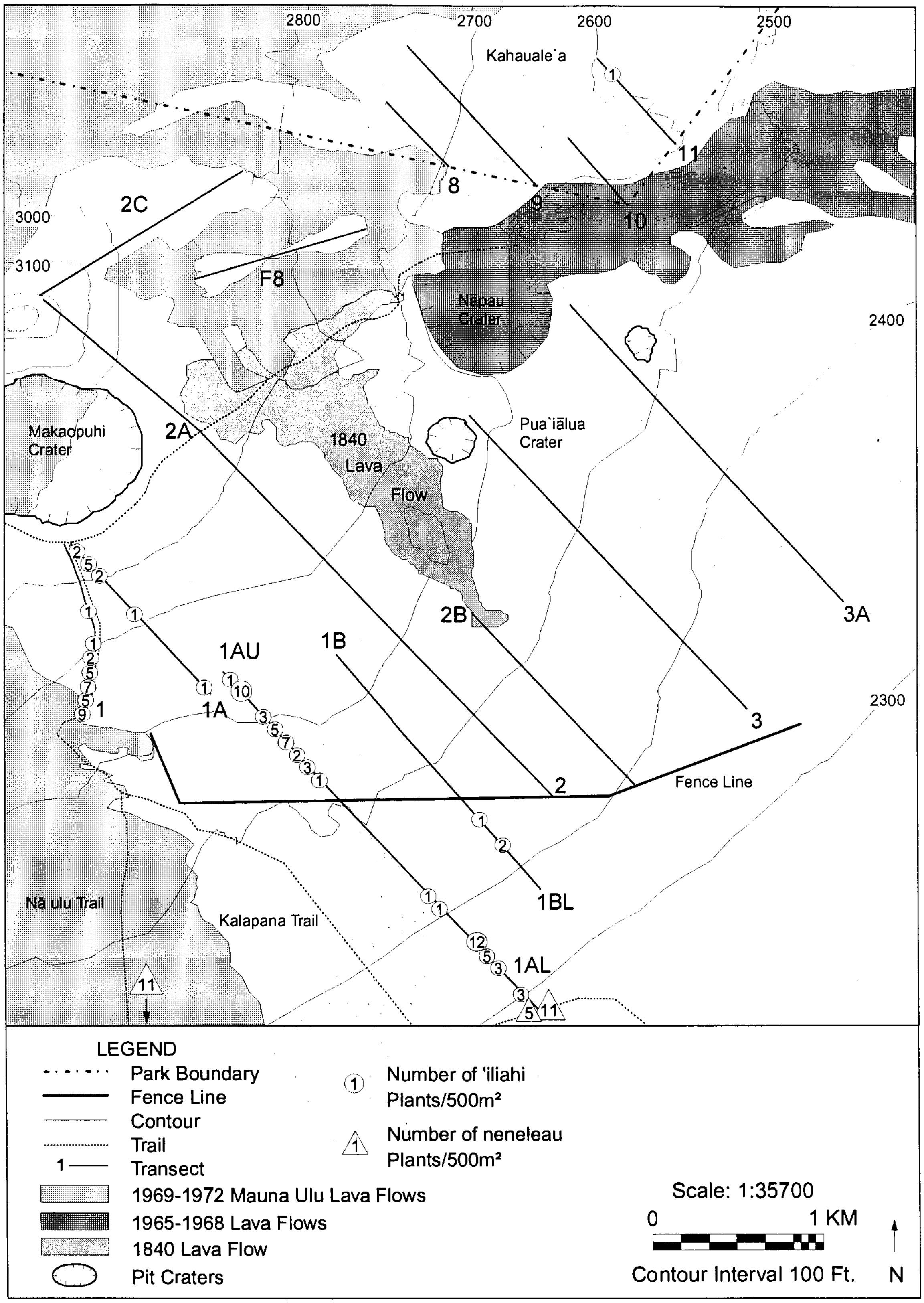


Figure 18. Distribution of 'iliahi (*Santalum paniculatum*) and neneleau (*Rhus sandwicensis*) in East Rift forests above a feral pig barrier fence, Hawaii Volcanoes National Park.

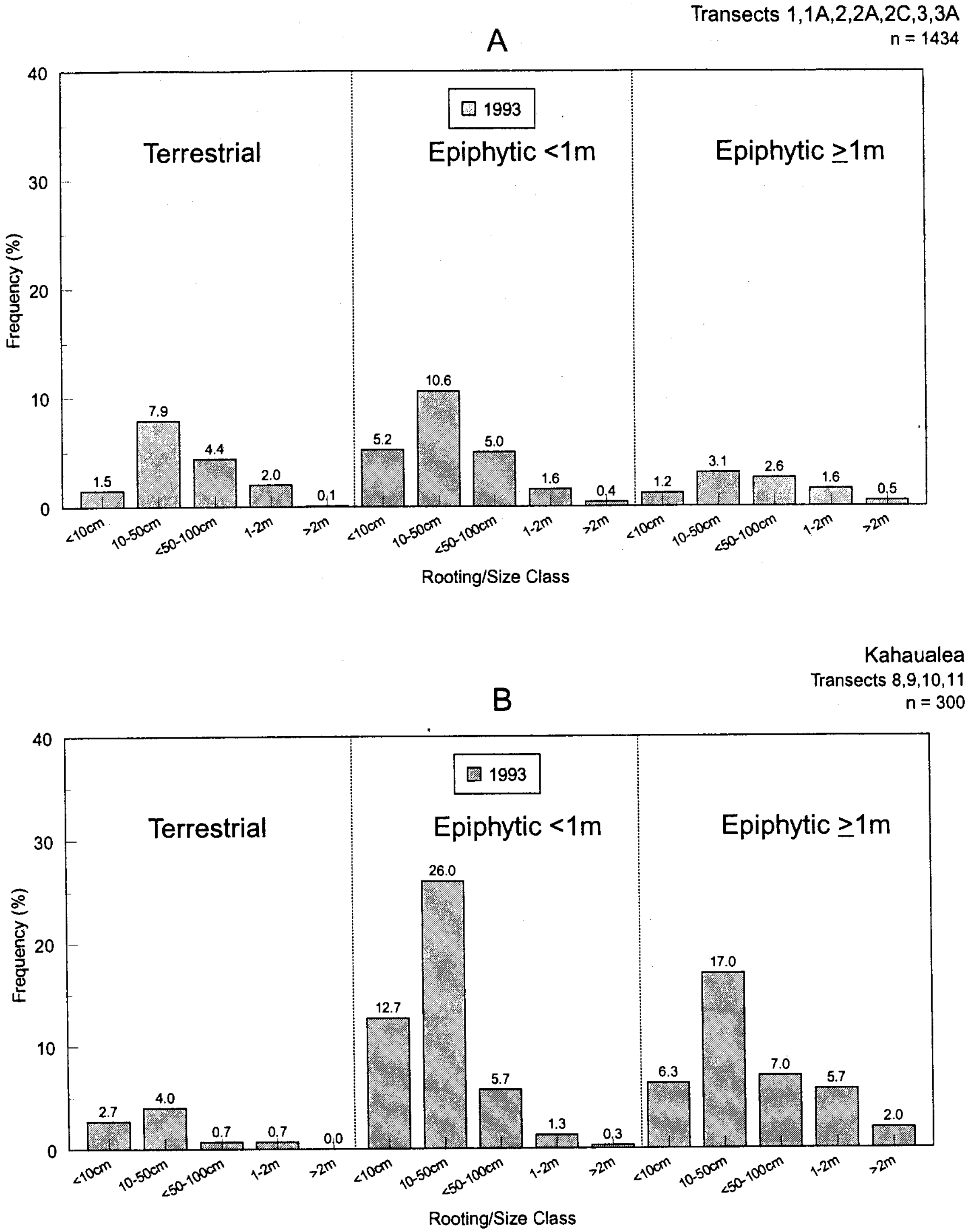
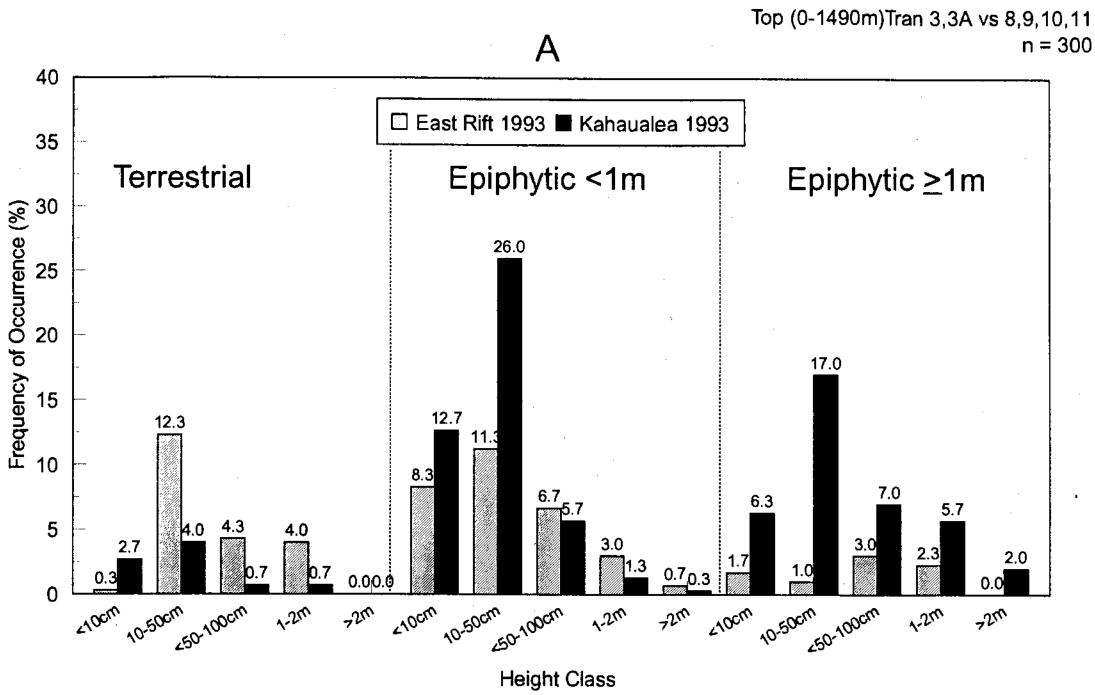


Figure 19. Frequency of 'ōhā (*Clermontia spp.*) in five height classes and three rooting categories along all primary transects in East Rift forests, Hawaii Volcanoes National Park (transects 1,1A,2, 2A,2C,3, and 3A).



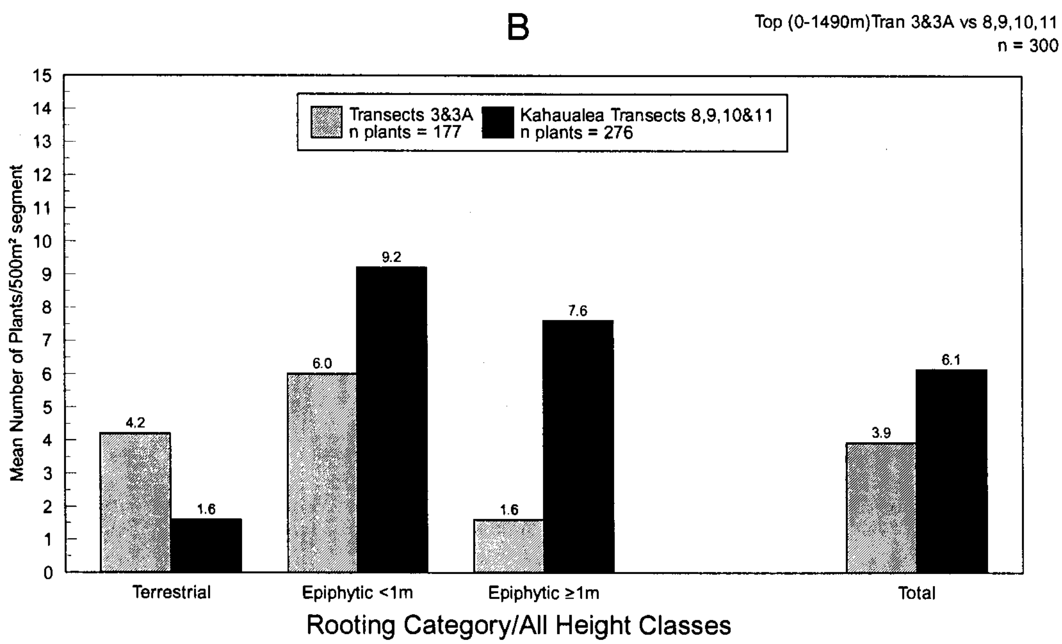


Figure 20. Frequency and density of 'ōhā (*Clermontia* spp.) in five height classes and three rooting categories along Kahauale'a transects and an equal length of transects (3 and 3A) in forests of Hawaii Volcanoes National Park.

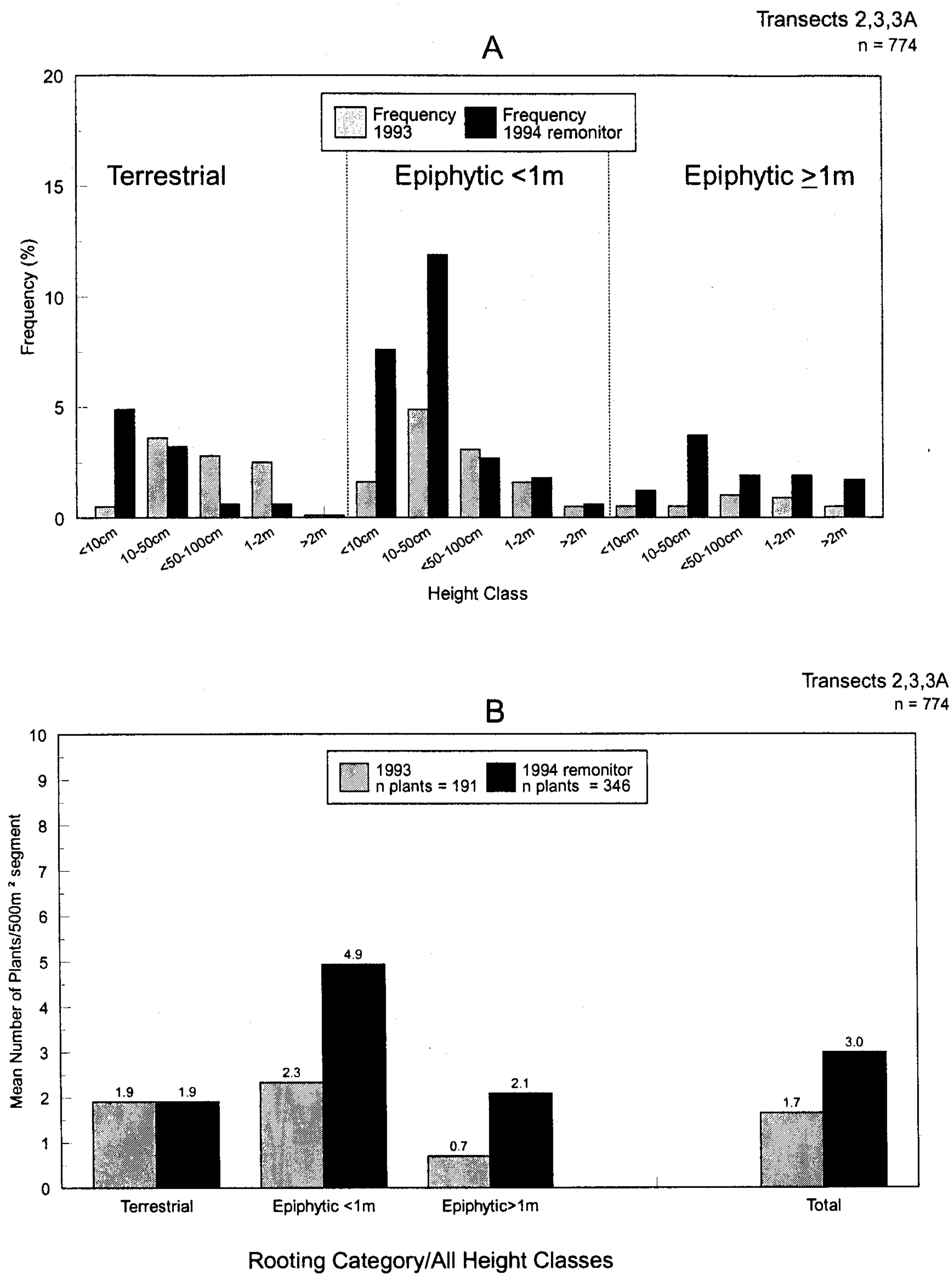


Figure 21. Frequency and density of 'ōhā (*Clermontia spp.*) in 1993 and 1994 along three re-monitored transects within forests of the East Rift, Hawaii Volcanoes National Park.

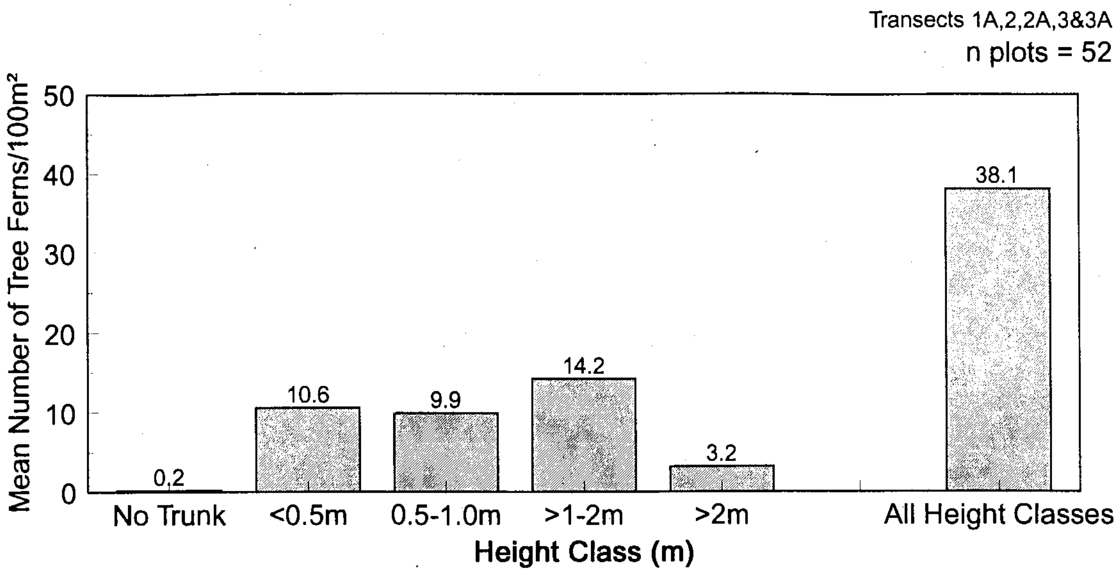


Figure 22. Density (mean no./100m²) of tree ferns (*Cibotium spp.*) in five trunk height classes along transects in East Rift forests of Hawaii Volcanoes National Park.

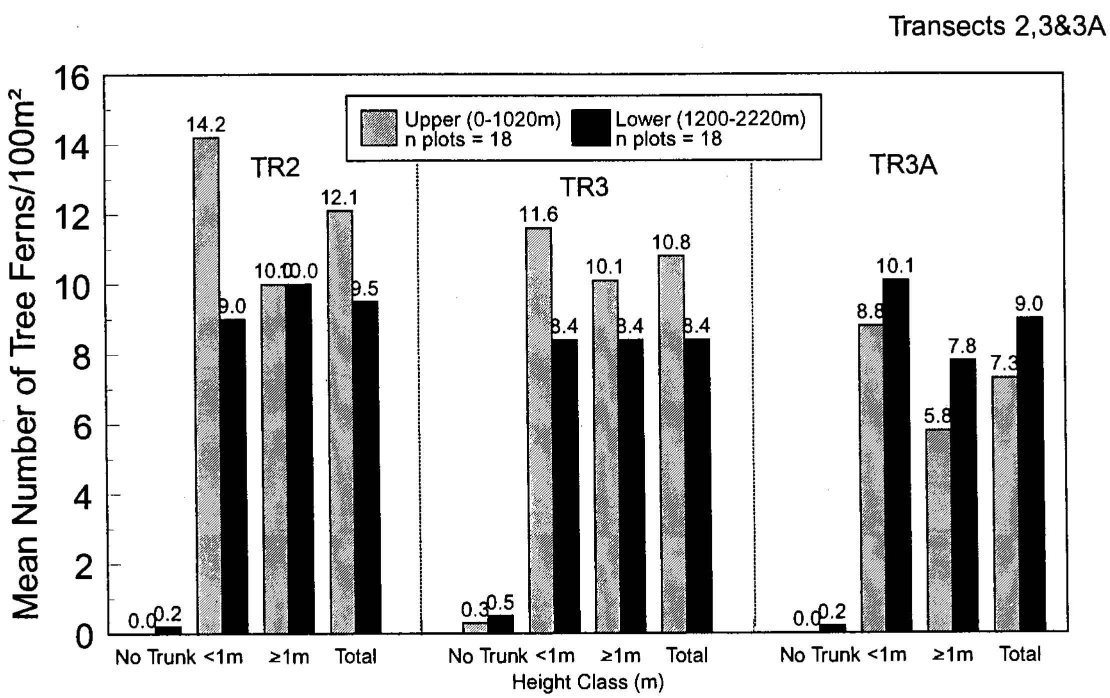
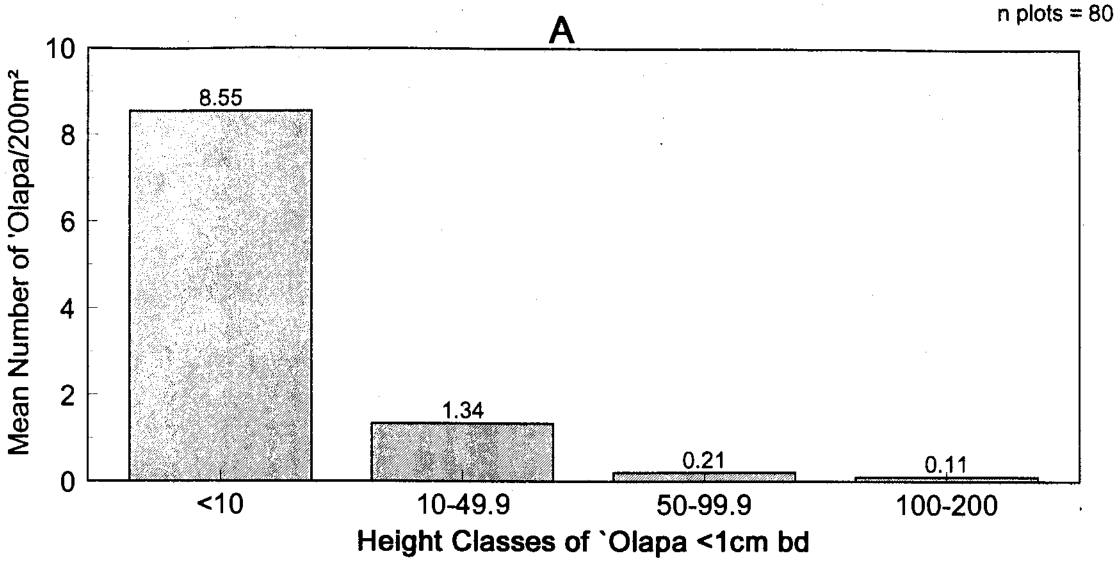


Figure 23. Density (mean no./100 m²) of tree ferns (*Cibotium spp.*) in three trunk height classes along the upper and lower halves of three transects in East Rift forests of Hawaii Volcanoes National Park.



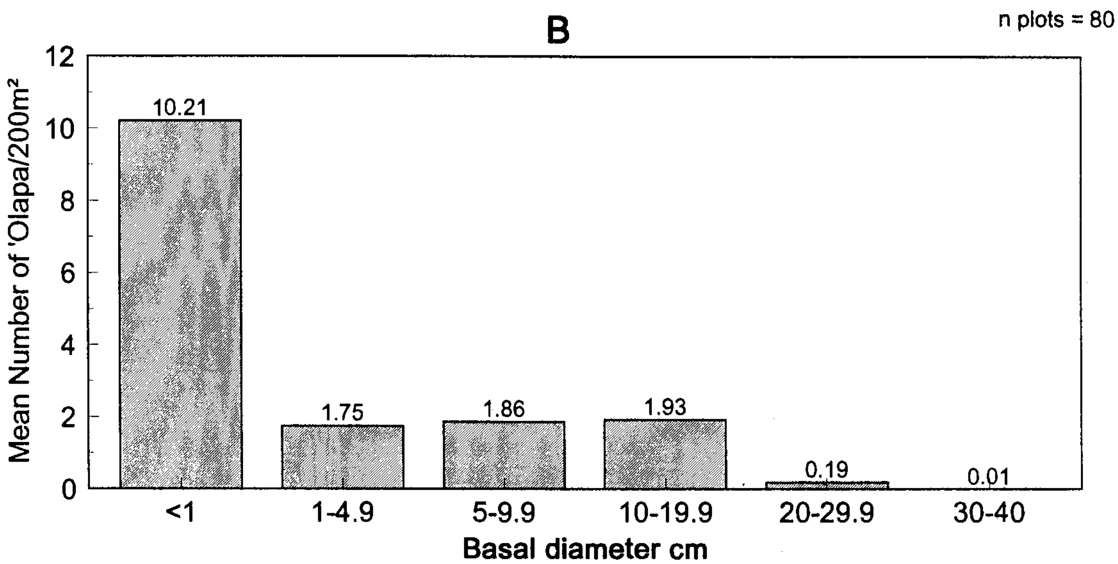


Figure 24. Size class distribution of 'ōlapa (*Cheirodendron trigynum*) in 80 plots along transects in East Rift forests of Hawaii Volcanoes National park.

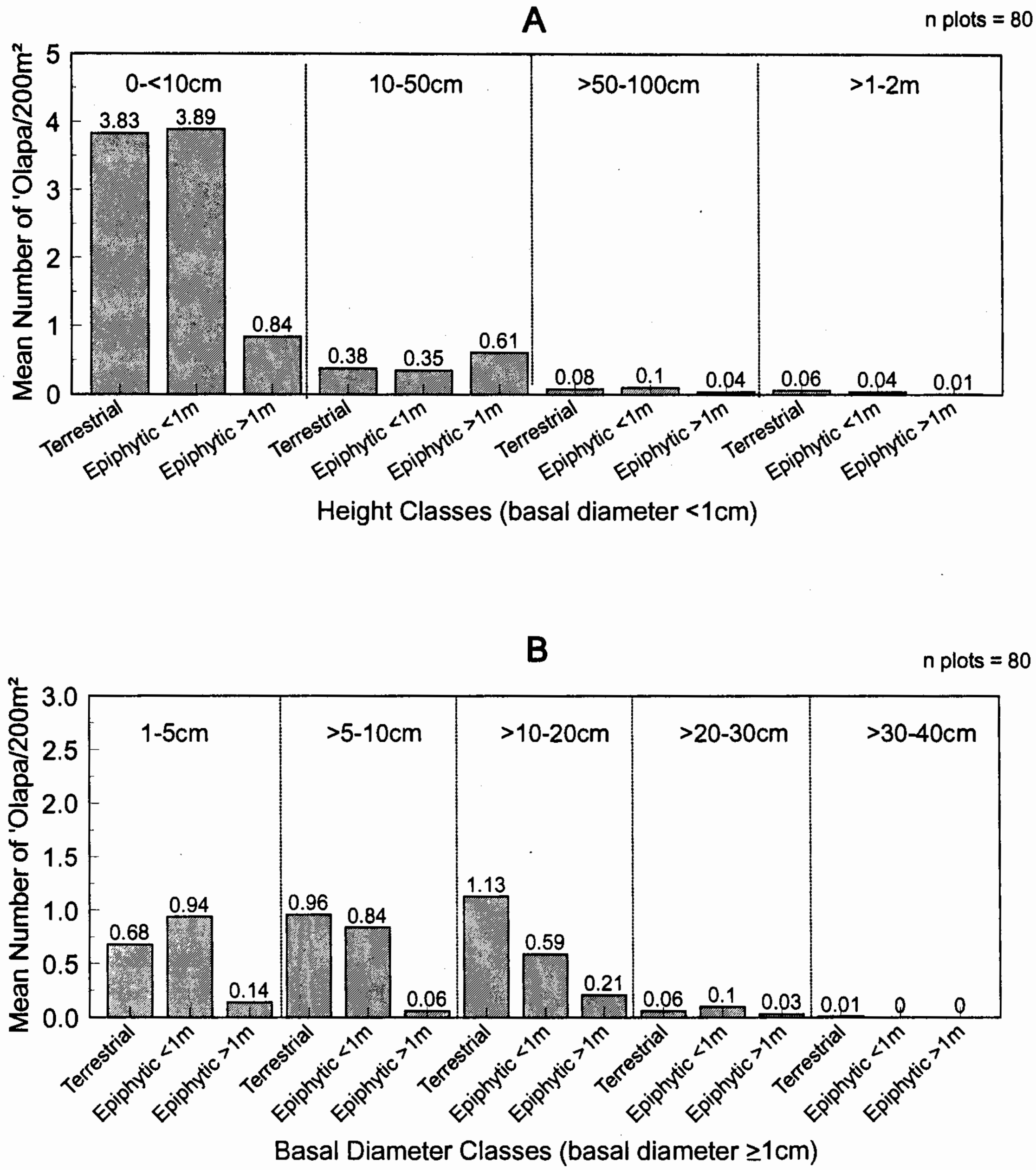


Figure 25. Density (mean no./200 m²) of `ōlapa (*Cheirodendron trigynum*) in height and diameter classes in 80 plots along transects in East Rift forests of Hawaii Volcanoes National Park.

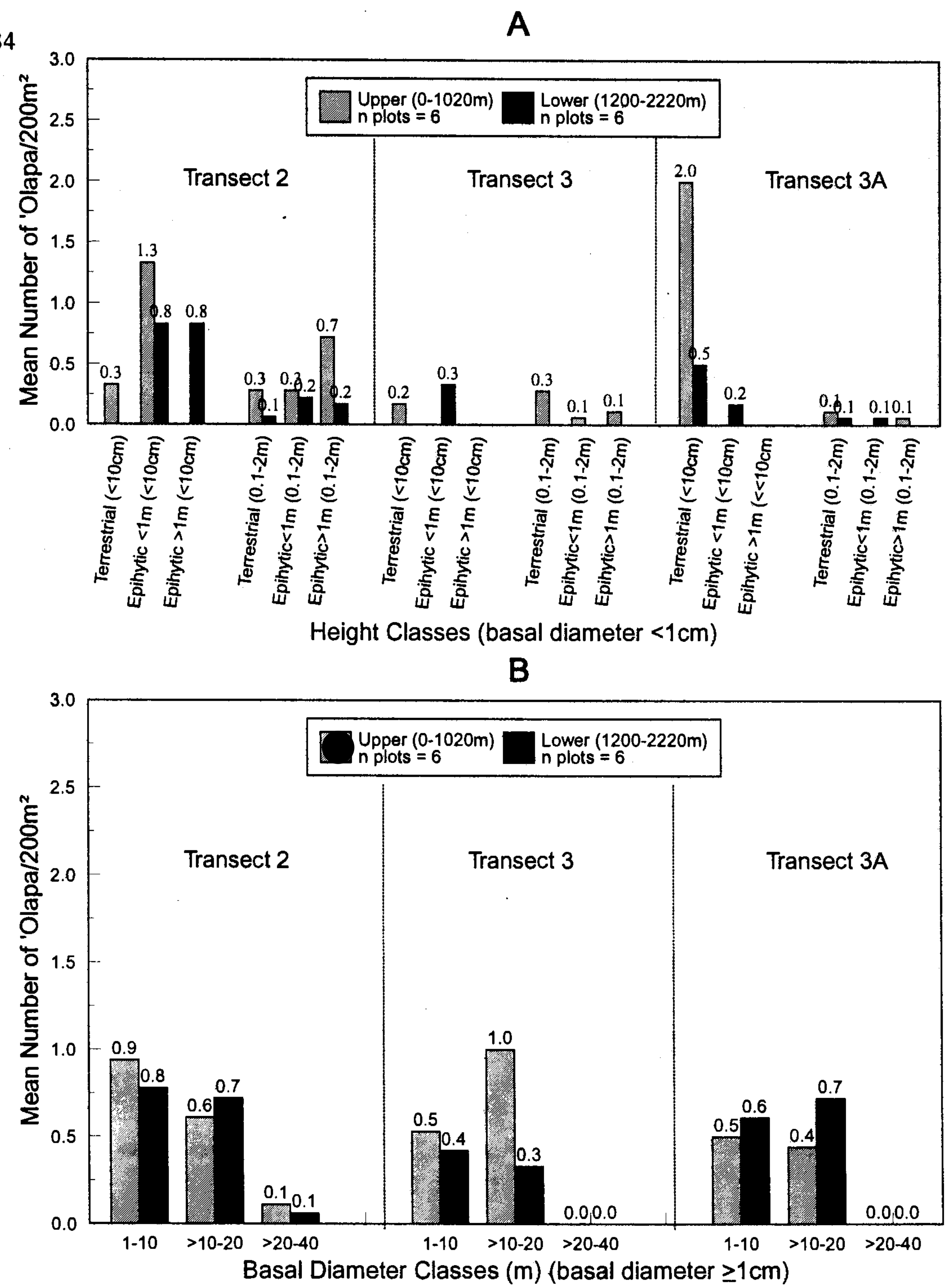


Figure 26. Density (mean no./200 m²) of `ōlapa (*Cheirodendron trigynum*) in height and diameter classes in plots along the upper and lower halves of three transects in East Rift forests of Hawaii Volcanoes National Park.

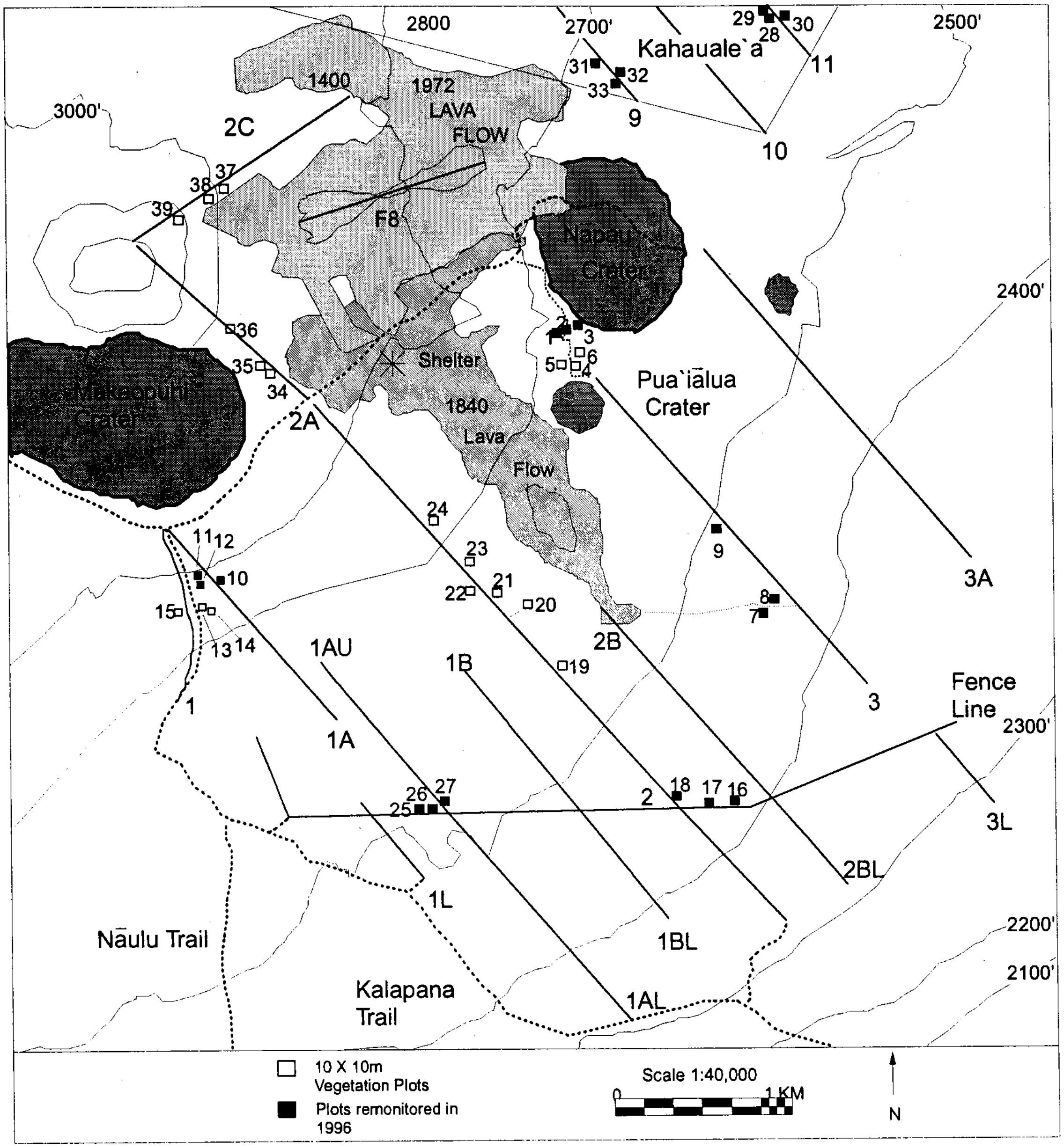


Figure 27. Location of pig-disturbed vegetation plots along transects and access routes in forests of the East Rift, Hawaii Volcanoes National Park and Kahauale`a.

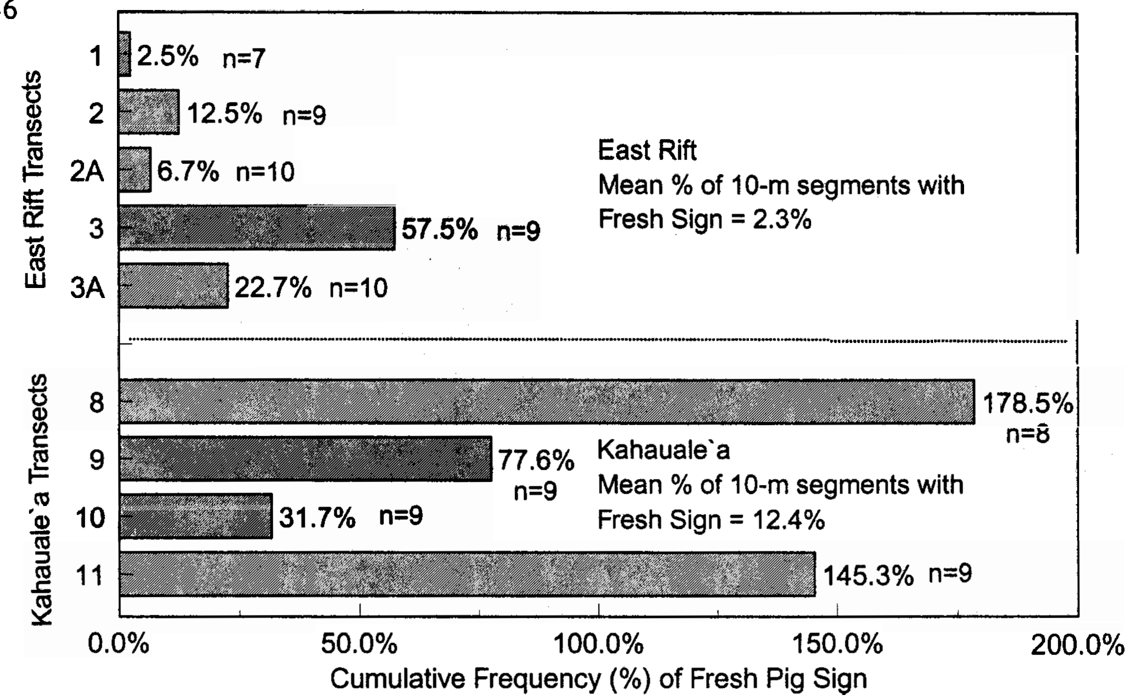


Figure 28. Cumulative frequency of fresh pig sign in East Rift forests along five transects in Hawaii Volcanoes National Park and four transects in Kahauale`a, June 1993-January 1996.

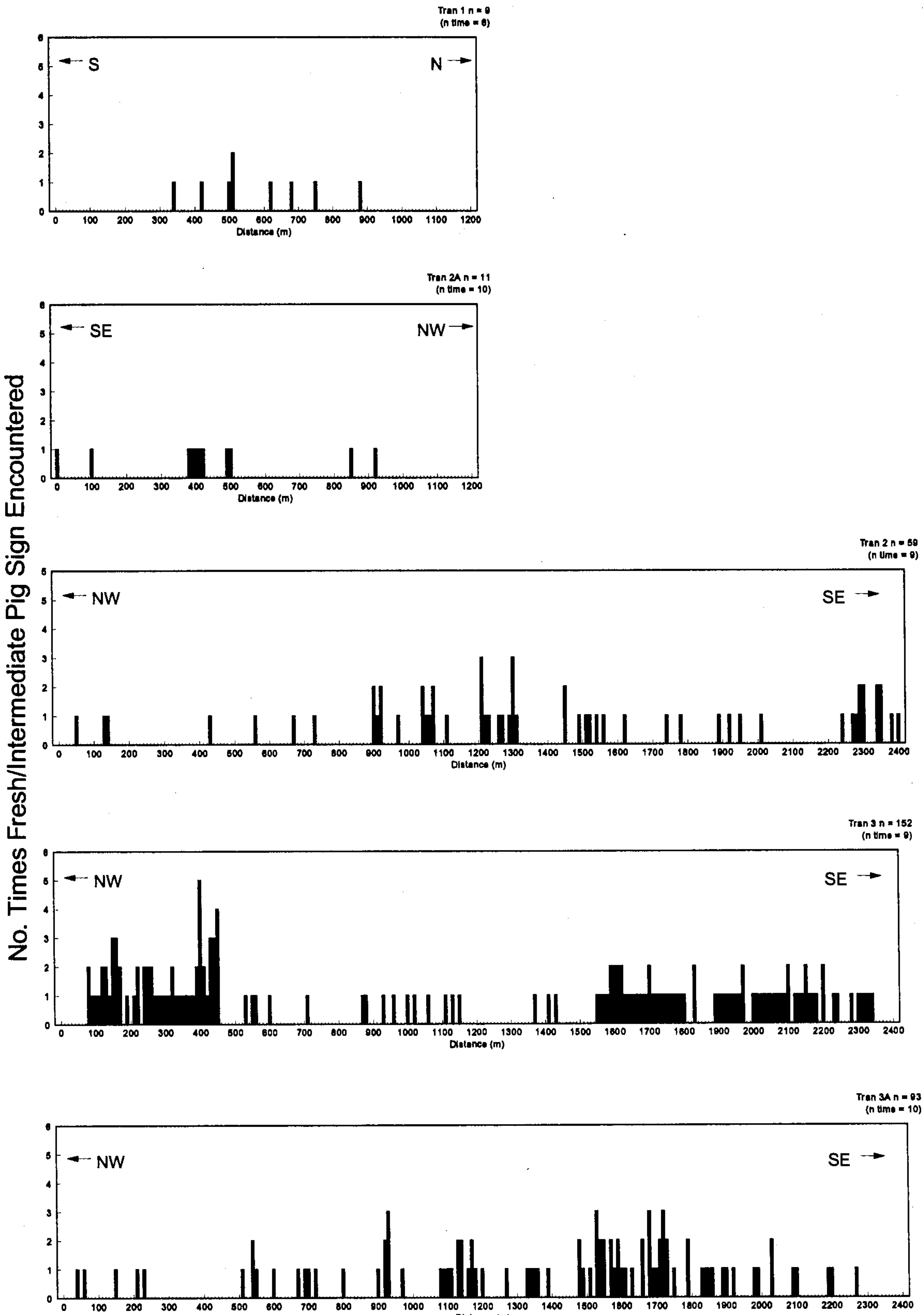


Figure 29. Temporal incidence of fresh and intermediate pig sign along five transects in forests of the East Rift, Hawaii Volcanoes National Park.

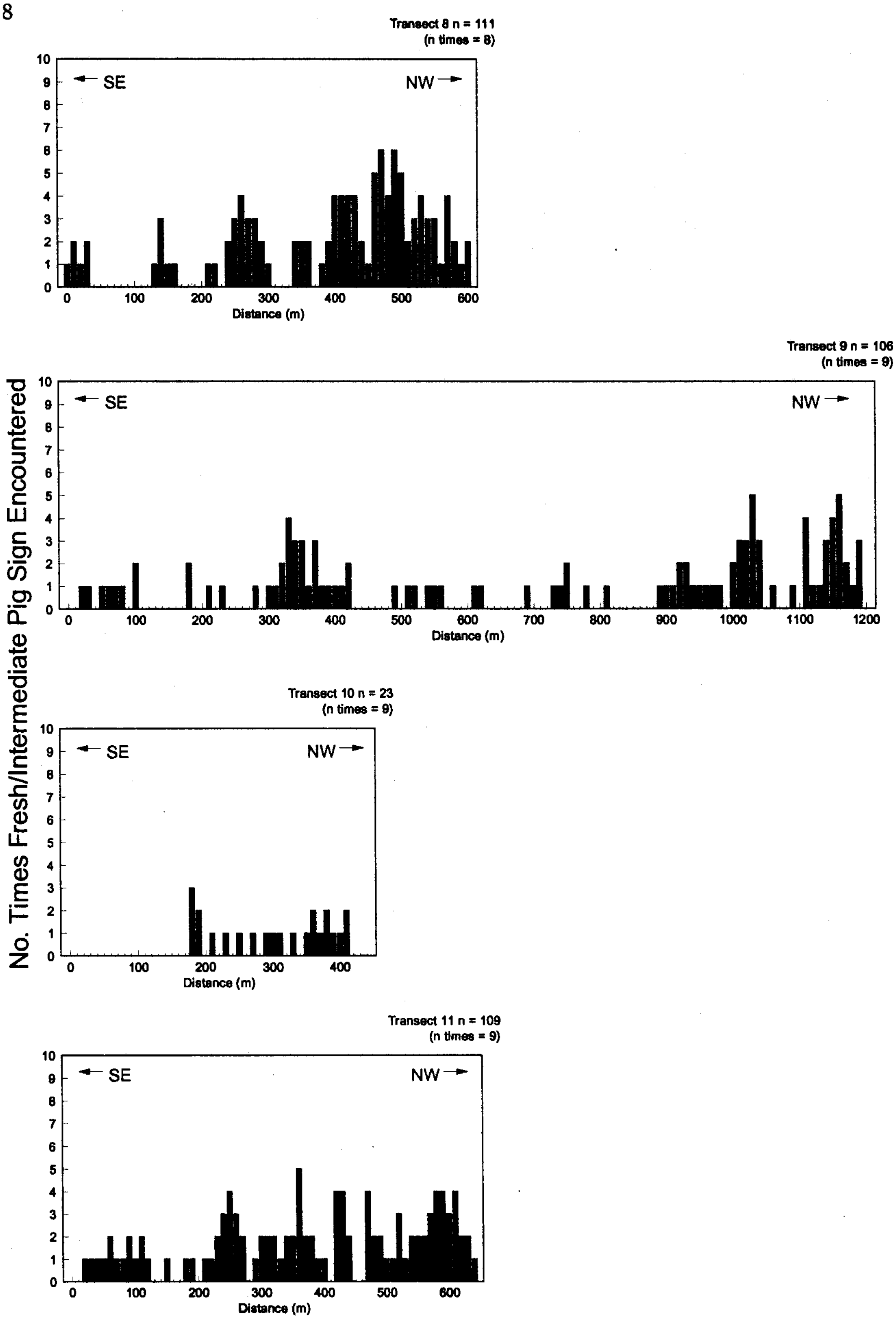


Figure 30. Temporal incidence of fresh and intermediate pig sign along four transects in Kahauale`a, adjacent to the East Rift study area in Hawaii Volcanoes National Park.